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CREVICE LEAD-ZINC DEPOSITS OF NORTHWESTERN ILLINOIS

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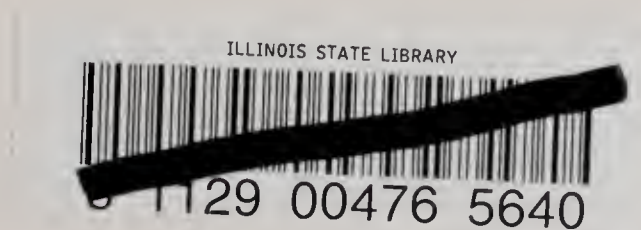
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CREVICE LEAD-ZINC DEPOSITS OF NORTHWESTERN ILLINOIS

J. C. Bradbury



Illinois State Geological Survey Report of Investigations 210
Urbana, Illinois

1959

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CREVICE LEAD-ZINC DEPOSITS OF NORTHWESTERN ILLINOIS

J. C. BRADBURY

ABSTRACT

The shallow crevice lead-zinc deposits of northwestern Illinois were an important source of lead in the middle of the nineteenth century but because of their small size and sporadic occurrence are not now generally regarded as economically valuable. An investigation was conducted to provide geological information that could be used to guide systematic prospecting and development and thereby renew interest in this neglected source of lead and zinc.

Structural and mineralogical studies were made of all active and many abandoned mines and prospects. Evidence suggests that crevice mineralization can be expected to occur at depths below those formerly mined. In new areas, geophysical and, more especially, geochemical methods of prospecting can be used to locate mineralized crevices that can then be tested for ore deposits by drilling. Drilling techniques and equipment now under development should be helpful in crevice prospecting.

A map shows the locations of areas of lead diggings and the directions of mineralized crevices. Information from old out-of-print publications is incorporated in summary form.

INTRODUCTION

The Illinois State Geological Survey in 1947 began a detailed study of accessible small, shallow lead-zinc mines in northwestern Illinois to determine the character and distribution of these crevice deposits and renew interest in these possible sources of lead and zinc ores. Thirteen mines and deposits have been studied, some of them active and some abandoned. Material on the dumps of former shallow lead mining operations was investigated to determine types of mineralization present in those areas. Crevice directions, as revealed by lines of pits or still open crevices, also were determined and mapped.

Results of the investigations are presented in this report. In addition, because much of the literature regarding the nature of the crevice deposits is in old out-of-print reports, some of the older data and concepts of origin are summarized.

HISTORICAL SUMMARY

The shallow lead-zinc deposits of the Upper Mississippi Valley mining region, of which those in northwestern Illinois are a part, were the nation's principal source of

lead ore between 1820 and 1865. Peak production was reached in the years 1845 to 1847 when the annual output was 27,000 tons of lead metal. As the known richer and shallower deposits were depleted, as market conditions changed, and as various factors adversely affected the supply of miners, lead mining declined to a fraction of its former importance. At present only a few hundred tons of ore are taken from the shallow deposits each year. Zinc, gained almost exclusively from the larger, deeper flat-and-pitch deposits, is now the chief product of the district.

ACKNOWLEDGMENTS

The 1947 field study was directed by R. M. Grogan, assisted by J. C. Bradbury. Investigations of current shallow operations since that time have been made by Bradbury, assisted by R. J. Cronk during 1951-54. Some of the illustrations and data included in this report are from earlier Survey studies by H. B. Willman, R. R. Reynolds, and Paul Herbert. Grateful acknowledgment is made of the help given by local mining companies, prospectors, and drillers without whose cooperation this investigation could not have been carried out.

CHARACTER OF THE DEPOSITS

Northwestern Illinois, especially Jo Daviess County (fig. 1), and adjacent parts of Wisconsin and Iowa contain deposits of galena, the common ore mineral of lead, which occurs in vertical joint-like fissures or crevices in the bedrock and as residual deposits at or near the surface of the ground. The deposits are commonly referred to as the shallow lead deposits or crevice lead deposits to distinguish them from the deeper deposits of zinc and lead found in the same general area.

The term "lead" was applied early to the deposits because the principal mineral then mined was galena. Some deposits, however, contain commercial amounts of the zinc mineral, sphalerite, and a few are primarily zinc orebodies with only traces of lead. The old terms "shallow lead deposits" and "crevice lead deposits" are here employed for convenience and because of former usage but with the understanding that some deposits contain zinc ores and that the word "lead" is used in the non-technical sense to refer to the mineral galena, not to lead metal.

The vertical joints along which the crevice deposits occur are oriented mainly east-west, although in limited areas in Illinois and Wisconsin the deposits occur in joints of various orientations. Such joints generally parallel each other within any specific area.

Along a typical single crevice, the ore shoots (minable concentrations) occur as pods from a few feet to a few hundred feet long scattered along the strike of the crevice. In shallow deposits controlled by two or more closely spaced parallel crevices, the ore minerals may be in small cavities or in narrow fissures distributed over a width of 30 feet or more and a length of several hundred feet.

Vertically, the ore deposits occur in certain favorable beds in the Galena Dolomite. Within a limited area the ore-bearing horizons may be stratigraphically constant, but they differ from place to place throughout the district.

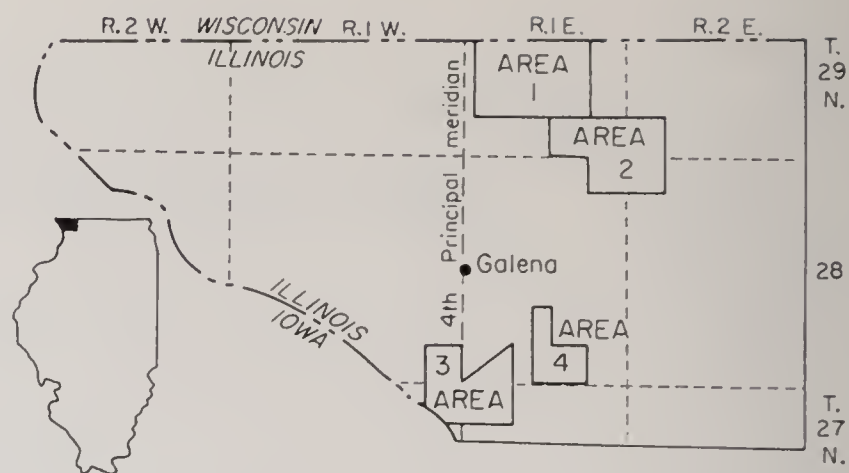


FIG. 1.—Northwestern part of Jo Daviess County, showing areas (1 to 4) in which studies were made of directions of joints. Small state map shows location of Jo Daviess County.

The original deposits are commonly modified by oxidation so that the wall rock surrounding the ore minerals is limonite-stained and greatly softened. In many places pieces of the minerals have fallen from the walls and become mixed with clay and dolomite sand in the open crevice.

The shallow lead deposits originated by the filling of open spaces along crevices. Depending upon the configuration of the original open spaces, there are four main types of ore occurrence: 1) fissure fillings; 2) deposits in brecciated rocks; 3) crystal-lined caves; and 4) surface residual deposits. Many deposits, although mainly of one type, include characteristics of one or more of the other types.

FISSURE FILLINGS

Form

Fissure fillings include "crevices," "verticals," "vertical sheets," "gash veins," horizontal sheets or "flats," and inclined sheets or "itches," and various modifications of these produced by post-ore oxidation and solution.

Crevice applies in a general way to vertical joint-like fissures that contain lead ore in various forms, but also specifically designates open fissures, sometimes called *verticals*, in which the mineral occurs attached to the walls. *Vertical sheets* of galena completely fill some fissures and range in width from thin films to several inches. A single vertical sheet seldom is minable, but orebodies may consist of several such sheets interlayered with barren rock in zones from

a few feet to 30 or more feet wide. The term "gash veins" was used by J. D. Whitney (1854) to distinguish the vertically limited, open, lead-bearing fissures of the Upper Mississippi Valley region from the "true veins" of other mining districts.

Flats are horizontal veins along bedding planes of the host rock, and *itches* are veins along inclined fractures. The *flat-and-pitch* type of lead deposit was important only in the Elizabeth area.

Effect of Post-ore Oxidation and Solution

Most mining in the crevice deposits has been above the water table, where original forms of deposition have been modified considerably. Oxidation of the sulfides, especially pyrite and marcasite, liberated sulfuric acid that in turn reacted with the dolomite wall rock. Open crevices have been widened and ore that was originally attached to the walls has fallen into the open space to become mixed with dolomite sand, clay, limonite, and the like. The resulting reddish brown mass of clay and sand is the miners' "ocher" and is characteristic of the shallow lead deposits. The cave-like opening above the ore-ocher mixture has commonly become partly or completely filled with laminated clay.

Weathering of the vertical sheet type of crevice deposit (narrow fissures filled with galena) seems unlikely to have resulted in many of the cave-like open spaces. In the two deposits of this type that were examined, the narrow vertical veins of galena were apparently still in place, but they were enclosed in walls of limonite-stained, disintegrated dolomite with, in places, a thin seam of clay between the galena and "rotten" dolomite.

Dimensions

Vertical sheets of galena range in width from less than 1 inch to about 4 inches. A number of sheets may occur along groups of parallel fissures spaced a few inches to several feet apart, thus forming a minable deposit as much as 20 to 30 feet wide. Open fissures (verticals) range from an inch or two to as much as 6 feet wide.

The height of the fissure-filling type of deposit is less easily defined because many

of the fissure-fillings pass downward into a breccia type of ore. However, according to published descriptions and field examinations, 5 feet is a characteristic height for the open crevice type. The one example of vertical sheet deposit studied, a 10- to 20-foot wide zone of parallel veins of galena, was worked for a height of 15 feet.

A continuously mineralized fissure, or group of closely spaced parallel fissures, may range from a few feet to as much as 1500 feet long, and possibly much longer. Cox (1914) states that the main orebody in the Royal Princess mine, California Digings area, was 2350 feet long, but it may be that several types of ore contributed to this great length.

DEPOSITS IN BRECCIATED ROCKS

Form

Deposits in brecciated rocks include the "honeycomb," "sprangle" or "brangle," "disseminated," and "stockwork" deposits. In honeycomb deposits the ore partly or wholly fills small irregular cavities, one-fourth of an inch to 2 inches across, in the host rock. Sprangle and brangle ores are variations of the honeycomb type that have generally larger mineral-bearing cavities. In stockwork deposits the mineral occupies a small-scale network of veinlets. Disseminated ore is honeycomb ore in which the cavities are very small. Because this is an incorrect usage of the term "disseminated," which denotes small grains scattered through a rock, it is not employed further in this report.

In all these varieties there is generally some evidence of brecciation and pre-ore solution of the rock. Some deposits are made up wholly or in part of angular fragments of rock surrounded by ore minerals. Others resemble vuggy rock with ore minerals in the vugs, and appear to have formed because of selective solution within the rock. Even in this type, however, angular fragments of chert have been found in what appears to be solid rock, suggesting brecciation of the rock followed by recementation.

Yet another type, seen at only one place, consisted of vug fillings of galena, one-half

to one-quarter inch across, rimmed with pyrite and apparently arranged along bedding planes in the rock. The rock was minutely fractured, with thin veinlets of pyrite a fraction of a millimeter to 2 millimeters thick along many of the fractures, but no part of the rock, including chert nodules, showed evidence of displacement.

A coarse variety of breccia ore is composed of rock fragments about 6 inches to 1 foot across with veins of sphalerite and galena separating the fragments. Locally, crushed zones that contain angular fragments of dolomite, one-half to 1 inch across, are associated with the coarse breccia. A relationship of the coarse breccia to honeycomb ore is illustrated in the Herman Smith mines No. 1 and No. 2 (figs. 6, 7). In mine No. 2 the upper part of the deposit is a cave lined with coarse galena crystals. Immediately below the cave is a coarse breccia with sphalerite-galena veins, changing downward into honeycomb sphalerite ore. Mine No. 1 contains the coarse breccia and honeycomb zones but lacks the galena coating on the walls of the cave.

Effects of Post-ore Oxidation and Solution

Post-ore oxidation and solution of the coarse breccias produced caves that later were partly filled with boulders and sand, the so-called tumbling openings. Weathering and disintegration of such deposits led Cox (1914, p. 55) to speak of "loose dolomite boulders heavily coated with blende" and to postulate that "deposition has taken place in part since the fall of this material from the roof."

The honeycomb deposits disintegrate to soft, buff to yellow-brown knots of dolomite in reddish brown dolomite sand. The spotted coloration led Percival (1855) to call the material "calico rock." Many of the cave or tunnel-like openings that characterize the crevice deposits within the zone of oxidation probably are the result of groundwater action on deposits of the breccia type. The large surface area that such deposits present to oxidizing agents and groundwater makes them especially susceptible to solution and disintegration.

Dimensions

Where the breccia type of ore accompanies the fissure-filling type, the dimensions are the same as those of the latter type except that the height of ore, generally 15 to 20 feet, is likely to be greater than that of the simple open-fissure type. Deposits primarily of the breccia type are generally 15 to 30 feet wide, 10 to 15 feet high, and 300 to 400 feet long.

CRYSTAL-LINED CAVES

Form

Crystal-lined caves constitute an uncommon group of deposits. Because the caves are rare, published descriptions are meager. Chamberlin (1882) saw only two of the deposits. Bain (1906) described one in the Royal Princess mine in the California Diggings area where crystal aggregates of sphalerite and galena resembling toadstools 3 to 6 inches in diameter projected 2 to 4 inches from the wall of a cavern.

In the Smith No. 2 mine (fig. 7), a sheet of galena lined a cave for at least 400 feet with only minor interruptions. The sheet ranged from a few inches to about 1 foot thick and showed cube terminations with edges up to 12 inches. The space inside the shell of galena ranged in height from about 2 to 6 feet and was commonly filled with laminated gray and brown clays. Directly below the galena shell the rock was a coarse breccia laced with sphalerite-galena veins. Weathering had softened and removed some of the dolomite host rock so that a space a few inches high between the galena "floor" (where still intact) and the underlying rock and ore was filled with clay. Downward, the host dolomite graded within a few feet to firm fresh rock, and at the base of the deposit the coarse breccia had changed to a honeycomb ore of zinc.

The height of the deposit varied but was generally about 15 to 20 feet. For much of its length the deposit appeared to be controlled by two or more joints that as seen in the mine roof were tight and apparently unmineralized. In a few places, however, a vein of sphalerite and galena extended into a central fissure above the galena shell.

Effects of Oxidation and Solution

Thorough oxidation of the sulfides with accompanying disintegration of the wall rock of a crystal-lined cave should produce the ordinary debris-filled cave. It is possible, then, that crystal-lined caves were not originally rare, but that post-ore oxidation and solution have made recognition of them difficult.

Dimensions

The few described crystal-lined caves range in height from 2 to 20 feet and are about the same in width. Apparently the maximum length for an individual cave is between 100 and 200 feet. The Smith No. 2 mine has been in this type of deposit for several hundred feet, but it has not been an uninterrupted galena-lined tunnel.

SURFACE RESIDUAL DEPOSITS

Surface residual deposits are mineral accumulations which resulted from the weathering of dolomite that originally contained lead deposits. Surface deposits were easily accessible and probably the first to be mined.

Residual accumulations of lead at the top of the bedrock have the same linear shape as the crevice deposits from which they were derived. Where a number of closely spaced crevices were present, the residual lead deposits, termed "patches" by the miners, may occupy a number of acres, although no specific figures are at hand. Chamberlin (1882) mentions that 2 to 3 million pounds of ore were taken from Big Patch, near Platteville, Wisconsin.

MINABLE EXTENT OF CREVICES

Lengths of individual deposits of different types have been described on preceding pages. A crevice may be opened, however, for a considerable length in order to mine several deposits along it. Bain (1906) states that because of the "softening of the rock (along a crevice) . . . an individual crevice may be followed underground for a mile or more."

Within an area of crevice deposits, the main crevices generally are in groups known as ranges. As explained by Leonard

(1897), the individual crevices of a range "are only a few feet apart and are connected by cross-fissures. The ore may give out in one, but will be found again in the next neighbor to the south." Leonard gives as an example the Timber range in the Dubuque, Iowa, area, which is "composed of three main crevices which are parallel, with several minor ones, and has a width of 100 feet. It has been worked for a distance of five miles or more, in some portions yielding lead and in others zinc." The common length of a range is one-quarter to one-half mile (Bain, 1906). The term "range" has also been applied to single crevices (Cox, 1914), probably those of considerable linear extent.

Vertical dimensions of the different types of crevice deposits have been described above. Two or more types may combine to give a height of 20 feet or more. Ore heights also increase considerably at "chimneys," vertical pipe-like mineralized zones that apparently occur at intersections of crevices. Bain (1906, p. 57) shows a diagram of a mine in the Dubuque, Iowa, area in which chimneys reached from one ore-bearing horizon to another, an interval of more than 50 feet.

Other exceptional heights along crevices may be due to post-ore solution. For example, in the Smith No. 1 mine the open space above the ore, commonly about 5 feet, at one place reached a height of more than 50 feet for a length of about 50 feet.

Crevice deposits have been found at intervals throughout the 250-foot thick Galena Formation, but the vertical extent of mineralization on a single crevice is not known because mining generally has stopped a short distance below the water table. Cox (1914) states that "usually no more than three openings (meaning mineralized horizons) will be found in a given vertical section," and Bain (1906) says that the crevice deposits commonly occur "within the first 100 feet of the surface." Both these statements, of course, are based on observations in mines that for the most part were limited in depth by groundwater.

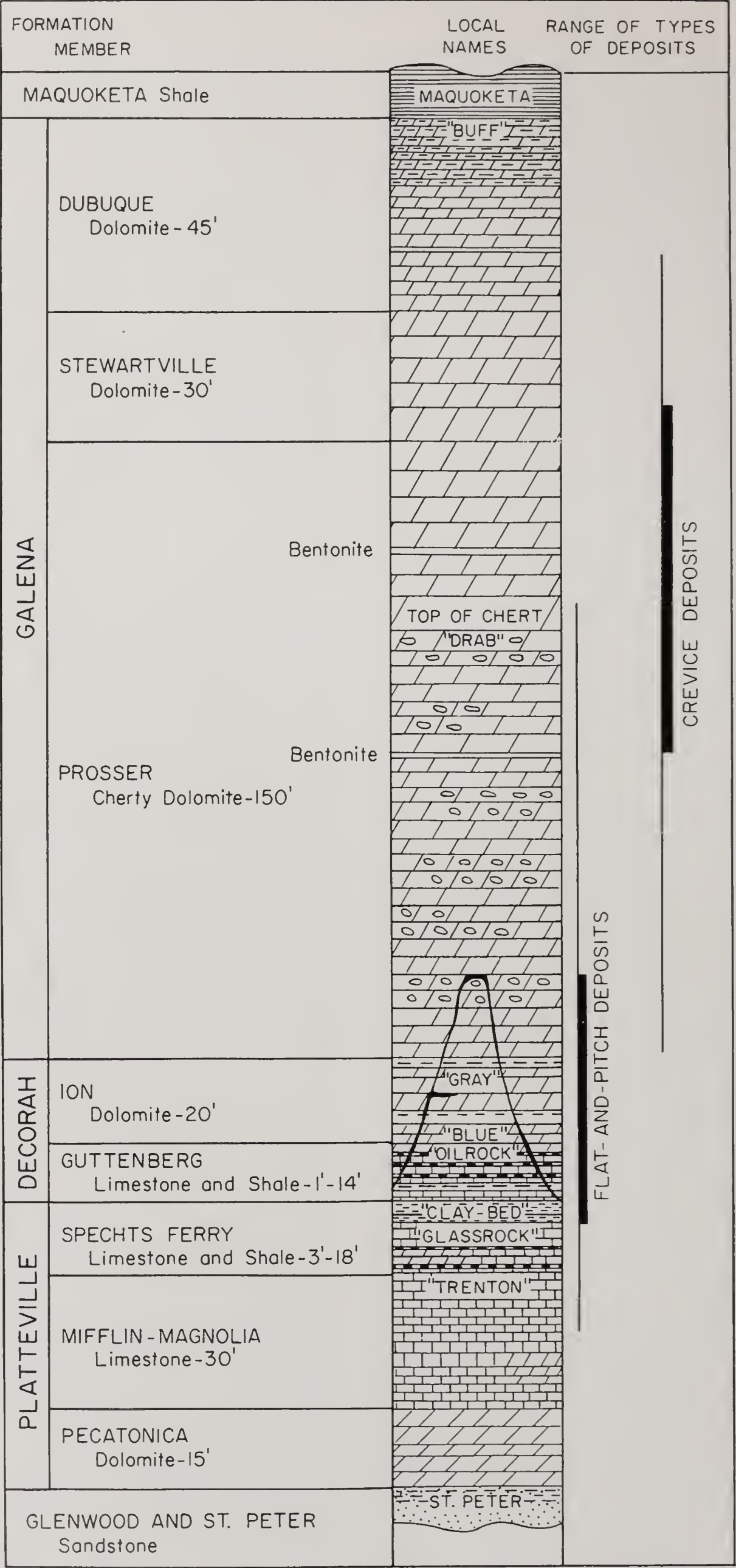


FIG. 2.—Middle Ordovician strata and stratigraphic range of ore deposits in northwestern Illinois (adapted from Willman et al., 1946).

GRADES OF ORE

Early reports on the shallow lead deposits gave only the number of pounds or tons of mineral taken from various mines and made no mention of the grade of the crude ore. Judging from our studies of old mines, the average content of galena probably ranged from 5 to 10 percent of the total volume of material moved by the miners. In terms of weight, as grade is commonly expressed today, this would be 14 to 25 percent galena (12 to 22 percent lead), using specific gravities of 7.5 and 2.5 for the galena and waste rock, respectively.* Remaining exposures of virgin ground in old mines in the California Diggings area would not average that high, and they may have been too lean for mining in the early days. Rich pockets run much higher than the average, probably well over 50 percent galena by weight, and are true bonanzas.

AREAL DISTRIBUTION

Five principal areas contained abundant shallow lead deposits (pl. 1): 1) the large area extending from Galena and its environs northeastward to Council Hill and northward to the state line; 2) the California Diggings area along the Mississippi River bluffs seven miles south of Galena; 3) the Elizabeth area; 4) the Apple River area; and 5) the Warren area.

Additional smaller groups of deposits were located southeast and northeast of East Dubuque, and near Scales Mound, Schapville, Millville, and Morseville (pl. 1). Outside the mapped area, in Stephenson County, a crevice mine near Freeport, about 45 miles east of Galena, and reported occurrences of lead near Oneco and Lena are mentioned by Shaw (1873, p. 72). A few small abandoned diggings also can still be found in an area between Savanna and Mt. Carroll in Carroll County, about 30 miles southeast of Galena.

Because the stratigraphic range of the

deposits is limited, and the region lacks pronounced folding and faulting, the areal distribution of the deposits is in part controlled by topography. Where valleys cut the ore-bearing strata and deposits cropped out, they were discovered and worked by miners. Where the favored zones have been removed by erosion there are no deposits, and where the Maquoketa Shale covers an area it may conceal deposits not discovered because of lack of outcrops.

As shown on the map (pl. 1), lead mining activities, commonly referred to as "diggings," were concentrated within the geographical groupings outlined above. Plate 2 shows two typical areas of diggings that illustrate the distribution of ranges and the close spacing of shafts and prospect pits characteristic of many areas. The close spacing of excavations has resulted in the rough surface presented by such an area today.

STRATIGRAPHY AND STRATIGRAPHIC DISTRIBUTION

STRATIGRAPHY

The stratigraphy of the zinc-lead district and the stratigraphic range of the ore deposits are shown in figure 2. Although the flat-and-pitch deposits are not discussed in this report, their stratigraphic position is designated in figure 2 to show the position of the crevice deposits in relation to the complete ore-bearing section.

The lithology of the formations is shown in figure 2, and, as this report is concerned chiefly with the deposits in the Galena Formation, the Platteville and Decorah Formations are not described further. For their detailed descriptions see Willman and Reynolds (1947) and Agnew et al. (1956).

The Galena Formation, which is the host rock of the shallow lead-zinc deposits, is a massive dolomite that forms vertical bluffs along the major streams. The Prosser Member is 150 feet thick and consists of a lower cherty portion 105 feet thick, locally known as the "Drab," and an upper non-cherty portion 45 feet thick. The up-

*Krey and Lamar (1925) report specific gravities ranging from 2.61 to 2.70 for Galena Dolomite from Jo Daviess County. The figure 2.5 is an arbitrary one, chosen as an approximation for the waste material of the crevices, which is mostly dolomite sand and clay in the rich cave-like pockets but may be relatively solid rock along the leaner portions.

per interval has no distinguishing local name of its own but with the overlying Stewartville and Dubuque Members is known as the "Buff."

The Prosser Member contains some more or less argillaceous zones, especially in the cherty portion, that weather more rapidly than adjacent beds and form reentrants on bluff exposures. Within the Prosser are two fairly persistent 1- to 2-inch bentonitic shale beds. The upper bentonite is 15 to 20 feet above and the lower about 30 feet below the top of the cherty portion (fig. 2).

Overlying the Prosser is the Stewartville Member, a uniformly massive, thick-bedded dolomite, except in the upper 10 feet where it becomes thinner-bedded as it grades into the overlying Dubuque Member. In the basal portion of the Stewartville the fossil sponge *Receptaculites* is abundant.

The Dubuque Member, the upper 45 feet of the Galena Dolomite, is in general thin-bedded and argillaceous and has many shale partings. Downward the beds increase in thickness and become less argillaceous as the Dubuque grades into the underlying Stewartville.

The upper Ordovician Maquoketa Shale underlies the upper slopes of the district, and the bluff-forming Silurian Dolomite caps the mounds and high ridges above the gentle slopes developed in Maquoketa Shale. As neither unit contains more than minor scattered occurrences of sulfides, these strata are not described in detail in this report. (See Willman and Reynolds [1947] for a detailed description of the Silurian strata, and Trowbridge et al. [1916] for the stratigraphy of the Maquoketa Shale.)

STRATIGRAPHIC DISTRIBUTION

Although crevice deposits have been found from the top to the base of the Galena Dolomite, they have been mined principally in the 130-foot interval that extends from the base of the Dubuque Member downward to some 55 feet below the top of the "Drab" (fig. 2). Throughout the

interval lead-zinc deposits may occur at any one of a number of stratigraphic positions, locally called "openings." According to Shaw (1873), one of the openings generally carries "the heaviest bodies of mineral" in any given vertical section on a crevice.

Names (for example, "first opening," "second opening," "pipe-clay opening") were given to certain portions of the 130-foot interval to designate the approximate stratigraphic location of crevice deposits. However, because mineralized horizons are stratigraphically the same only within small areas (Cox, 1914), the names have only a loose application. Unfortunately, their use has led to the false notion that only certain limited portions of the 130-foot interval are favorable for mineralization.

The stratigraphic position of an opening generally is determined by a caprock, a more resistant bed 6 to 8 inches thick, underneath which the rock has suffered more intense fracturing, more solution, or both. Within a deposit the caprock may form a flat unbroken roof, the crevice may breach the caprock and, gradually narrowing, terminate somewhere above it, or the crevice may widen again and proceed upward to the next caprock, 5 to 10 feet above. In this manner a body of ore may alternate between two or more stratigraphic horizons several times throughout its length.

The existence of potential caprocks throughout much of the Galena Formation is suggested on exposures along bluffs where weathering reveals subtle differences between rock layers. In addition, a study of logs of prospect holes, on which have been recorded any cavities or soft ground struck by the drillers, indicates that caves may occur at many different horizons within the Galena Formation.

STRUCTURAL RELATIONS

The shallow lead deposits were formed along fractures, apparently shear joints, of great linear extent, as much as two miles long in the Dubuque, Iowa, area. Most of

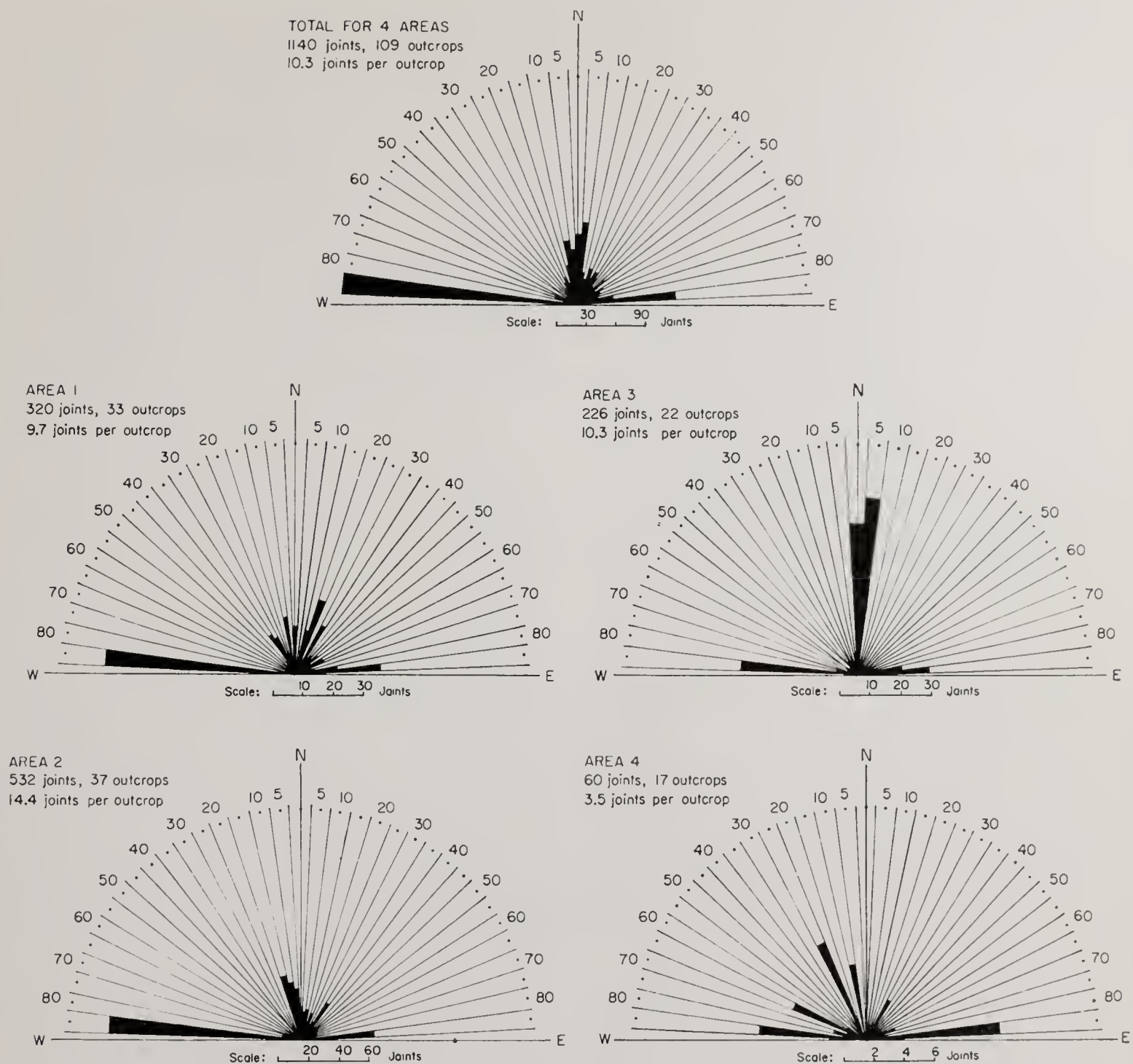


FIG. 3.—Diagrams showing directions of strike of vertical joints in northwestern Illinois lead-zinc district. Top diagram is a summation of the other four, which correspond to the areas shown in figure 1.

the fractures are vertical, although inclined fractures are not uncommon. By far the greatest number of mineralized fractures in northwestern Illinois trend approximately east-west, although crevices trending north, northwestward, and northeastward also have been mined, especially in the Council Hill area.

The directions of joints in the northwestern Illinois district were measured from 109 outcrops in four different areas within the district (fig. 1). The composite joint diagram (fig. 3), shows that the dominant direction of strike is approximately east-west. Diagrams of joints in each of the four areas also are shown in figure 3. For the most part, all joint directions present in the district are repre-

sented in each area but in different proportions for each area. The one exception is area 3 where almost the only directions represented by the joints are approximately east-west and north-south. Little is known concerning the strike of the mineralized crevices in area 3, but Bain (1906, pl. VII) shows a few crevices that strike about N. 70° W.

The interpretation of the fractures as shear joints that resulted from regional compression is based on their great length and on their characteristics and patterns in underground exposures. In the Smith crevices and in several crevices in the California Diggings, particularly in barren ground, it was evident that the locus of deposition was a zone of closely spaced

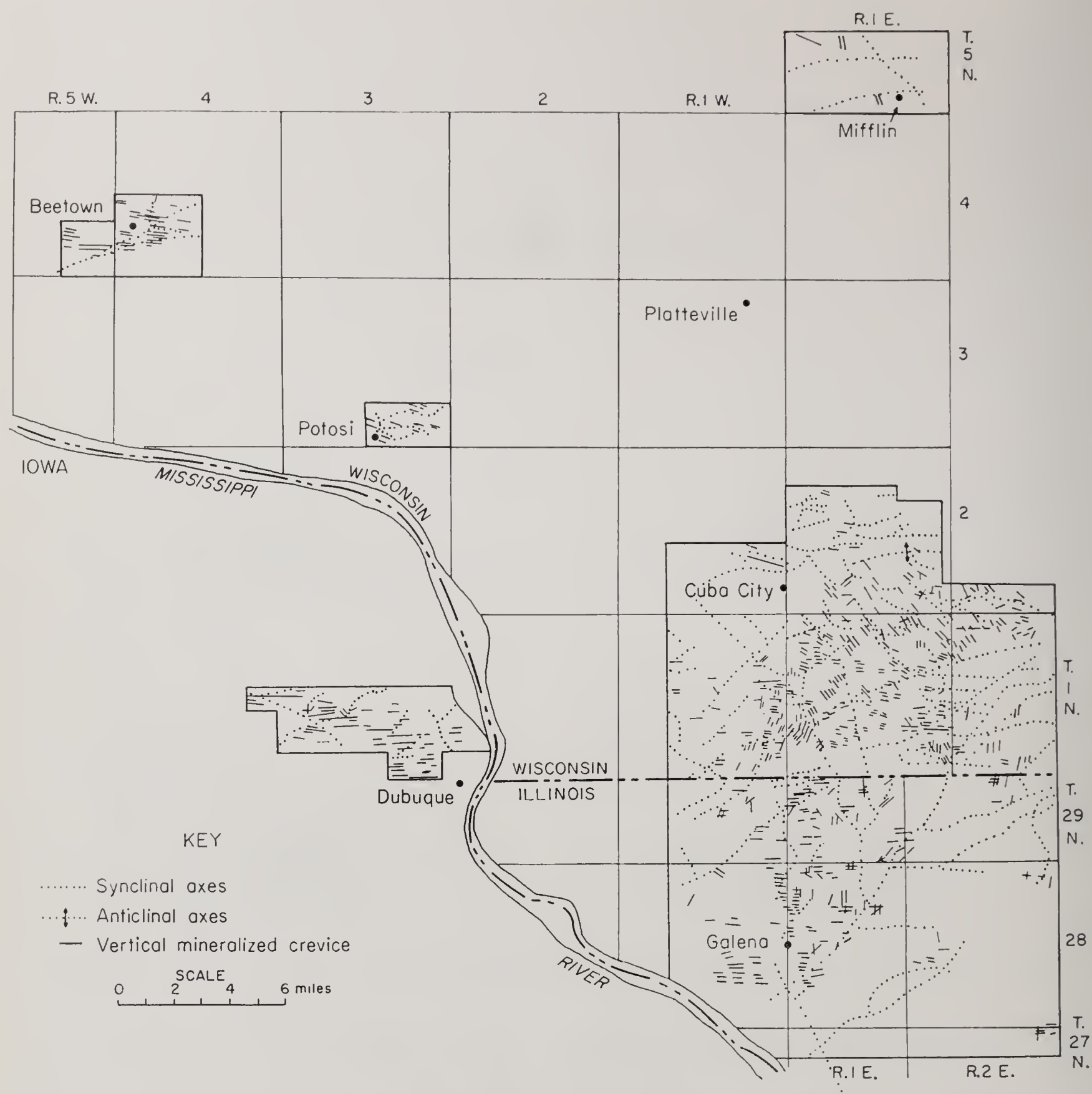


FIG. 4.—Directions of strike of crevice deposits and folded structure in Upper Mississippi Valley district. Density of distribution of the lines is proportional to the actual density of distribution of the deposits as far as known, but each line does not necessarily represent a single crevice or a specific group (range) of crevices. Directions of crevices in Illinois taken from Illinois Geological Survey field maps and notes compiled by H. B. Willman and R. R. Reynolds; in Ts. 1 and 2 N. in Wisconsin, crevice directions taken from Bain (1906, Pl. VII); crevice directions in remainder of areas taken from U.S. G.S. Mineral Investigations Field Studies Maps and from Strategic Minerals Investigations Preliminary Reports (1946-1955), listed in References. Trends of folds taken from same U.S.G.S. maps for Iowa and Wisconsin and from Bradbury et al. (1956) for Illinois.

fractures rather than a single clean break. Furthermore, brecciation may be recognized in honeycomb or brangle ore that is not too badly disintegrated by weathering. Intense crushing is indicated in limited areas where ore minerals cement angular rock fragments one-half inch or less in diameter.

Figure 4 shows the trends of crevices and folds for those areas for which structure contour maps have been published and in which the structural trends are reasonably well established. The pattern of folding is shown by the axial trends of synclines. One anticline, in T. 2 N., is shown because it is the dominant structural

feature in that area. Otherwise, synclines are equal to or exceed the anticlines in prominence.

The major folds (fig. 4) trend northeast to east-northeast and are intersected by subsidiary folds that trend northwestward and eastward. The major northeastward trending folds are broad, gentle structures, whereas the subsidiary folds are typically narrow and well defined. Amplitudes range from 10 to 50 feet but are typically about 30 feet.

The broad, persistent northeastward trending synclines are probably the result of compressional forces (Heyl et al., 1955; Willman et al., 1946), but the narrow, generally sharp synclines trending northwestward and east may be due to solution of the limestones in the lower part of the ore-bearing section (fig. 2) with attendant sagging of the overlying strata (Willman and Reynolds, 1947). The subsidiary synclines are associated with the deeper-lying flat-and-pitch orebodies, but they appear to have no direct influence on the crevice deposits. For this reason, and because their mode of origin is in doubt, they are not considered in the following discussion of the relationships of trends of folds and crevices.

A general correlation exists between the trends of the crevices and the major folds (fig. 4). In areas where the dominant trend of the folding is northeastward (as in the Galena-Cuba City, Dubuque, and Beetown areas), the crevices are dominantly east-west. East of Cuba City and in the Potosi and Mifflin areas, the major folds trend more nearly east and the crevices trend northwestward, as if the whole system were rotated in a clockwise direction. In local detail, however, the correlation is not perfect.

More than one period of deformation for the Upper Mississippi Valley region must have been necessary for the development of the observed relations. If the joint system were already in existence at the time of formation of the northeastward trending folds, the compression from the southeast would have caused shearing

along the east-west joints and would have made them more favorable as ore receptacles. In those areas in which the major axial trend of folding has swung to the east, the ore-bearing crevices trend northwestward, which is the corresponding shear direction to a north-south compressive force. With the dissipation of shearing stresses along pre-existing joints, local changes in trend of the major synclines would be likely to have little effect on the crevice trends. Evidence that the Upper Mississippi Valley region was subjected to more than one period of diastrophism is found in the Illinois Basin (Weller and Bell, 1937) where deformation occurred at various times throughout the Paleozoic era.

Groups of crevice deposits that do not conform to the main trends of the district can be attributed to special conditions that operated only locally.

MINERALOGY OF DEPOSITS

PRIMARY MINERALS

The primary, or original, minerals of the shallow lead deposits are galena, sphalerite, pyrite, marcasite, and calcite. The secondary minerals, or those introduced after the deposits were formed, are the common oxidation products of the sulfides and include anglesite, cerussite, smithsonite, and "limonite." A black, powdery substance found in pockets and streaks in the debris fill contains a large percentage of manganese, according to a qualitative spectrographic analysis by K. B. Thompson (1949, personal communication), and is probably "wad," a mixture of hydrous manganese oxides.

Galena

Galena (lead sulfide), the ore mineral predominant in the shallow deposits, may occur in thin sheets filling fractures about 1 mm. wide or as linings of caverns or open fractures where the crystal terminations may show cubes as much as 1 foot or more on an edge. Typically, however, masses of cubic crystals occur in the clay and dolomite sand fill of the crevices. Galena may

also be found intergrown with sphalerite or as small masses or individual cubes generally about one-quarter inch on an edge, scattered in the dolomite host rock. The dominant form of galena is the cube, but the octahedron may be present as minor modifications on some of the cubes or as small, late, octahedral crystals.

Sphalerite

Sphalerite (zinc sulfide) is fine- to medium-grained, infrequently coarse, and occurs in single crystals, radiating aggregates, or sheet form. Radiating aggregates, varying from a few mm. to more than 2 cm. in diameter, are the common form in honeycomb and brangle deposits. Single crystals also occur in the honeycomb type of deposits.

In sheets of sphalerite the individual grains are roughly parallel and are oriented with their long axes normal to the vein wall. Some sheets appear to have begun as radiating aggregates, as shown by radiating patterns in the sphalerite next to the wallrock. An individual sheet, as half of a symmetrical vein or as a coating on the walls of a cavity, is typically about 1 cm. thick, but thicknesses from 5 mm. to 5 cm. are common.

Individual blades of the radiating aggregates and sheets are 0.5 mm. to 2 mm. wide and 1 mm. to 1 cm. long. Single crystals are commonly 2 mm. across but vary from 1 mm. to 5 mm.

Crystal habit is fibrous to bladed in the radiating aggregates and sheets. Most single crystals are too complex and distorted to classify as to habit, but a few tend to the tetrahedral form, with an occasional good tetrahedron truncated on the edges by the cube.

Color banding, or zoning, is common in the sphalerite. The color bands, generally parallel to the periphery of a single crystal or radiating aggregate, range from light yellow through yellowish brown to dark reddish brown and in most specimens form an early light-colored zone, a middle dark-colored zone, and a late light-colored zone. In some specimens, however, several repe-

titions of the light and dark zones may occur, or one or two of the zones may be missing.

Pyrite

Pyrite (the isometric crystalline variety of FeS_2) is fairly abundant in the unoxidized portions of the deposits, and pseudomorphs of "limonite" (goethite) after pyrite are common in the oxidized portions. The grain size is normally fine, about 1 mm., but fairly coarse crystals are common. Octahedrons of pyrite measuring as much as 8 mm. on an edge are found in specimens from the Little Giant and Smith No. 2 mines.

The octahedron is the only form of pyrite found in the veins and veinlets, but some of the very fine grains (0.1 mm.) scattered in the wallrock are cubes. Other tiny grains in the wallrock appear to be octahedrons, and more nearly rounded grains may be pyritohedrons or combinations of the octahedron, cube, and pyritohedron.

An uncommon occurrence of cubo-octahedrons lined a small (3 by 10 mm.) cavity in a specimen from the wallrock of the Smith No. 1 mine. The crystals were minute (0.3 to 0.5 mm.) but, viewed under the binocular microscope at a magnification of 36X, were clearly cubo-octahedrons. In most of the crystals the cube and octahedron were developed equally, but on some the octahedron was dominant, and on a few the cube was the major form. The octahedral faces showed overgrowths of minute pyrite crystals but the cube faces were smooth. The unusual feature of this occurrence is the comparatively large size attained by forms other than the octahedron. A comparable occurrence was found in the California Diggings area where cubes of goethite after pyrite were found in a vug in the wall of one of the adits.

Microcrystalline pyrite, identified by means of X-ray diffraction by W. F. Bradley, occurs as concentrically layered spherical or hemispherical aggregates from 1 or 2 mm. to 1 cm. in diameter. The pyrite is dark greenish gray and earthy on the upper surface of an aggregate where it is not

covered by another sulfide. On a broken surface, however, it has a metallic appearance. Some preferred orientation of the individual grains is evident in the radiating fibrous structure shown by the aggregates. The constituent grains of the aggregates apparently are not firmly interlocked, as shown by the fact that a finger lightly rubbed across one of the masses becomes smudged. Aggregates of this type have been called "melnikovite-pyrite" and assigned a metacolloidal origin (Palache et al., 1944).

Marcasite

Marcasite (the orthorhombic variety of FeS_2) generally occurs with the pyrite and is similar in grain size. Crystals are most commonly tabular but some are columnar with a diamond-shaped cross section. The columns generally are terminated by low domes. A medium- to coarse-grained, fibrous variety of marcasite occurs in botryoidal aggregates that have the typical pale brass color of marcasite and contain thin shells of pyrite.

Calcite

Calcite is uncommon in the crevice deposits. It was found in only one of the deposits examined where it filled the central part of a galena vein. The mineral was massive, coarse-grained, and cloudy white in color.

As calcite is known to be a relatively soluble mineral under conditions of weathering, its absence in most crevice deposits may be partly the result of the generally weathered state of these deposits. It seems likely, however, that calcite was never deposited in great abundance in the crevices. If it had been, one would expect to find at least remnants of it in many more places.

SECONDARY MINERALS

Cerussite

Cerussite (lead carbonate) occurs on the surface of galena crystals as a coating of small, colorless, transparent to yellow-gray, opaque crystals or as a thin, powdery coating that generally is in two or more layers of various shades of gray and ranges from paper thin to 1 to 2 mm. thick. The crys-

tals are about 0.5 mm. long, but some may reach 1 mm. They commonly are tabular but of complex development. The crystals may rest on a layer of powdery cerussite or lie directly on galena. The thin, powdery coatings were identified as cerussite by their effervescence in acid and by X-ray diffraction of two samples (W. F. Bradley, personal communication).

Anglesite

Anglesite (lead sulfate), commonly the first oxidation product of galena (Boswell and Blanchard, 1927), appears to be extremely rare in the Upper Mississippi Valley district, for though it has been reported its presence has never been substantiated (Bain, 1906; Cox, 1914). During the present study many pieces of galena were examined to determine the identity of oxidation products, but no anglesite was found in the oxidized crevice ores. However, a sample of galena from the upper part of the stratigraphically lower Bautsch zinc-lead orebody, four miles south of Galena, was found to be coated by tiny white crystals, identified as anglesite by optical methods. This occurrence of anglesite, in place of the otherwise universal cerussite, is probably due to the fact that oxidation was slight and to the presence of a supply of sulfate ions from a much larger quantity of sulfides than was available in the smaller crevice deposits. The second is apparently the deciding factor, as slightly oxidized galena from the crevice deposits is coated only with cerussite.

Smithsonite

Smithsonite (zinc carbonate), also popularly called "dry bone," is the common weathering product of sphalerite. It is not at present mined as an ore of zinc, but at the turn of the century it was more important than sphalerite (Bain, 1906). The smithsonite may be pseudomorphous after sphalerite, or it may coat other minerals or line fractures in the dolomite host rock. In all its occurrences it appears to be made up of tiny aggregates of radiating fibrous crystals, and, where it has grown into an open space, it always presents a botryoidal

or reniform surface. Color varies from creamy white to brown, but in the aggregate the over-all color is brown.

The most interesting occurrence of smithsonite is its pseudomorphic replacement of a layer, or sheet, of sphalerite. The original color banding of the sphalerite is preserved in various shades of brown in the smithsonite. A hydrochloric acid etch of a ground surface of smithsonite normal to the banding shows that the dark brown and dark reddish brown bands of the parent sphalerite are now iron-rich smithsonite, whereas the lighter colored portions of the former sphalerite are now relatively pure smithsonite with streaks and patches of limonite. The bands and streaks of limonite-rich material show a cellular structure on the etched specimen, with the cell walls chiefly parallel to the banding. Prolonged solution in hydrochloric acid leaves a residue of thin flakes of silica, probably the "jasperoidal silica" that commonly forms in the weathering products of sphalerite (Boswell and Blanchard, 1927).

No hemimorphite was recognized in the ores.

Limonite

"Limonite" is a general term applied to hydrous iron oxides that form as a result of the oxidation of iron-bearing minerals. In the northwestern Illinois deposits limonite occurs as yellow, brown, or reddish brown stains, powdery coatings, and crusts on the minerals and wallrock of the oxidized parts of deposits and in the crevice fill. It also occurs as pseudomorphs after crystals of pyrite and marcasite and has been found in beds one-quarter to one-half inch thick interstratified with clays in the caves above oxidized ore deposits where it apparently was deposited as a gel by groundwater. These limonite layers are brittle and crumbly, probably because of shrinkage cracks formed when the gel dehydrated.

To determine the mineral constituents of the limonites, three types were subjected to X-ray analysis: 1) limonite pseudomorphs after pyrite; 2) limonite beds from cave fill; and 3) cellular boxwork from

oxidation of sphalerite, including some "fluffy limonite" (Boswell and Blanchard, 1927) that had been deposited in the boxwork. Samples 1 and 2 contained goethite and amorphous material; sample 3 contained smithsonite as a crystalline phase, but no crystalline "limonite." As the amorphous material of the "limonites" is probably essentially hydrous iron oxide (except for the silica of the boxwork of sample 3) it can correctly be termed limonite (Palache et al., 1944).

Wad

A black, powdery material, locally called "lampblack" and found in streaks and pockets in the debris fill of the crevices, has been identified tentatively as wad, a mixture of hydrous manganese oxides, on the basis of its appearance and a qualitative spectrographic analysis by K. B. Thompson (1949) that showed manganese as the main element present. An X-ray diffraction diagram of the material showed only a small amount of crystalline material, which appeared to be carbonate and was probably admixed dolomite grains from disintegrated rock.

The source of the manganese is probably the dolomite host rock, which in general has suffered extensive solution during oxidation of the sulfides. Spectrographic analyses of 36 samples of Galena Dolomite from outcrops and quarries in the zinc-lead district show that the dolomite normally contains .03 to .05 percent manganese (Juanita Witters, personal communication). One type of pyrite and the dark red color bands in the sphalerite contain close to .01 percent manganese, but, taken as a whole, the manganese content of the sulfides averages less than one-tenth that of the dolomite.

Although Chamberlin (1882), Bain (1906), and Cox (1914) suggested the presence of alabandite, no manganese sulfide has ever been found in the sulfide ores of the district, so it seems probable that the sulfides contributed little manganese to the segregations of wad. Another possible source of manganese is calcite, samples of which from two different mines have been

found to contain some manganese (qualitative spectrographic analysis by K. B. Thompson, 1948). This source, however, is difficult to evaluate because there is little evidence regarding the amount of calcite deposited in the crevice ores.

Clays

The laminated clays that surround the fallen chunks of ore minerals and nearly or completely fill most of the caverns vary from gray and buff through various shades of brown to black. Apparently most of the clays were introduced into the crevices from sources other than the host dolomite. The clays of the Smith crevices are chiefly montmorillonite, with some limonite present in the darker-colored layers. Identification was based on differential thermal analyses by W. A. White and on X-ray powder diffraction patterns by W. F. Bradley. The minus 2-micron fraction of the loess overlying the Galena Dolomite at the Smith No. 1 mine also proved to be mainly montmorillonite, and it is presumed that the loess is the parent material of the clay fill. An X-ray diffraction diagram of the residue from an acetic acid digestion of a sample of Galena Dolomite showed illite and chlorite as the only identifiable clay minerals. A certain diffuseness of the illite peak may have been caused by the presence of "degraded mixed-layer clays," according to Bradley, but no montmorillonite was indicated.

Black clay with thin gray laminations occurred as a layer 1 foot thick near the top of the clay sequence in Smith No. 1 mine and also as pockets and veins in the ore below the layered clay sequence. A spectrographic analysis by Witters found the black clay contained only about .02 percent manganese, indicating that it is not a segregation of wad. Differential thermal analyses showed the clay from the 1-foot bed and from the veins to be chiefly montmorillonite with a small amount of carbon and pyrite, both of which may contribute to the black color. A cross section of the cover at the top of the bedrock exposed at the entrance to the mine showed under the loess a bed of black silty material 6

inches to 1 foot thick containing plant remains. The black silt, when burned free of organic matter, was almost identical with the overlying loess in grain size and mineralogy. The black organic silt deposit, probably of Pleistocene age, is a reasonable source for the black clay of the crevice fill.

In the California Diggings area in the Mississippi River bluffs south of Galena, the crevice clays apparently came from different sources. Judging from remnants left in pockets along the cave walls, the top foot or so of the clay fill, which composes about half the full thickness of the clays, consisted of pink and gray laminated clays. The clays are similar in appearance to Pleistocene terrace clays along the Galena River where they were exposed in a "borrow pit" during construction of the floodwall at the city of Galena. An X-ray diffraction pattern (W. F. Bradley) of the pink and gray clay from the crevice showed mostly montmorillonite with some illite and had the pattern of a loessial clay. It is presumed, therefore, that the pink and gray clays are derived from loess and are backwater fill from the Mississippi River.

Beneath the pink and gray clays is a succession of clays grading from gray-buff through brown and reddish brown to black, like those found in the Smith mine crevices. X-ray diffraction patterns of two different strata of the gray-buff California Diggings clays showed illite present and chlorite probable, but no mineral was designated "abundant" because of the poorly defined patterns. The origin of such a clay is indefinite. The Galena Dolomite, the illite-chlorite-bearing Maquoketa Shale (which overlies the Galena at the top of the bluffs) and deposits of glacial till are possible sources. Beavers et al. (1955) found that illite and chlorite are the principal clay minerals in Wisconsin till and soils derived therefrom in northeastern and eastern Illinois. As the zinc-lead district lies within the driftless area, there are no local deposits of glacial till, but it is possible that the Mississippi River carried in suspension clays derived either from

tills of adjacent areas or directly from the melting ice and deposited them in the quiet water of the caves in the bluffs.

The Galena Formation seems the more likely source of the clay for two reasons: 1) its proximity; and 2) the poor quality of the diffraction patterns of the clays, which is typical of clays residual from carbonate rocks, according to Bradley.

The thin seams and small pods of a black powdery substance in the California Diggings clay, according to a qualitative spectrographic analysis by K. B. Thompson (1949), are primarily manganese oxide, wad.

PARAGENESIS

The sequence of deposition (fig. 5) was, in general, pyrite, marcasite, sphalerite, galena, marcasite, and calcite, but variations, overlappings, and repetitions are common. The veins and irregular cavity fillings show the crustification and banding that is characteristic of open-space fillings (pl. 5A).

Pyrite and marcasite were the first minerals deposited. As shown by studies of polished sections, pyrite is the earlier, and at places the only, iron sulfide deposited prior to sphalerite. Its earlier forms apparently are cubic and cubo-octahedral. Scattered grains of marcasite may be present with the pyrite, both in the veins and in the wallrock, or the marcasite may have become abundant enough toward the end of the pre-sphalerite phase to form a rim on the pyrite next to the sphalerite. The amount of iron sulfide at the edge of a

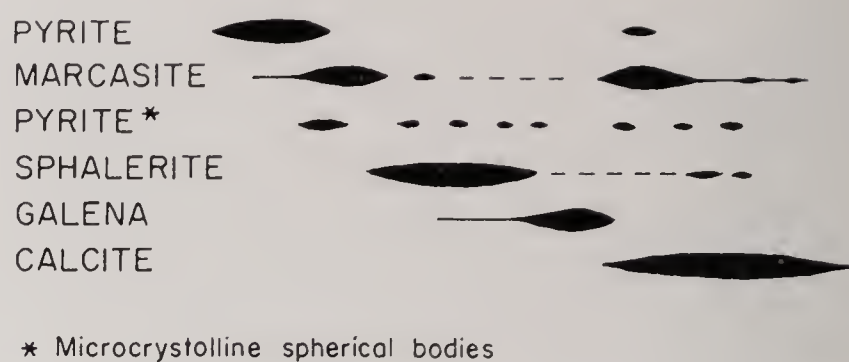


FIG. 5.—Diagram showing sequence of mineralization in crevice deposits. Age of mineralization decreases from left to right.

vein may range from a few scattered grains to a layer one-quarter inch thick. In the wallrock the iron sulfide rarely impregnates the dolomite heavily but commonly lines the vugs. The vug linings may show either the early cubic or later octahedral variety of pyrite and commonly may have an outer layer of marcasite, indicating that iron deposition in the wallrock continued in favored spots as long as it did along the fissure walls.

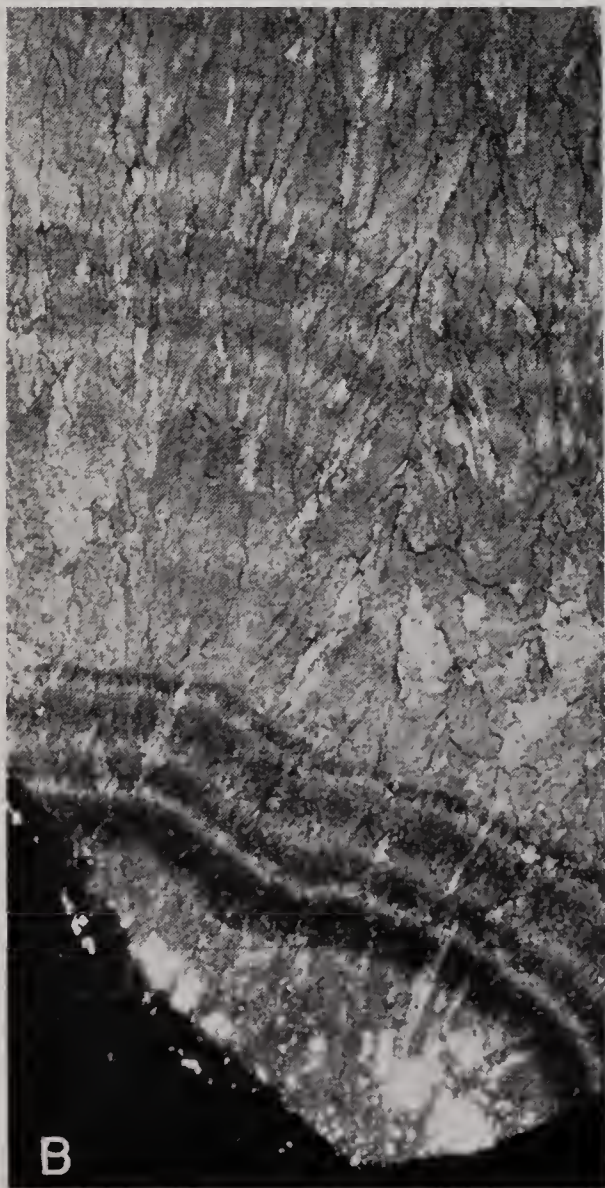
Sphalerite overlies and tends to corrode pyrite and marcasite. The color banding in the sphalerite shows a definite age succession—a light-colored early zone, a dark-colored middle zone, and a light-colored late zone (pl. 5B), although in places one or two of the color zones may be missing. The light-dark-light sequence may be repeated one or more times (pl. 5C).

Soft globules of microcrystalline pyrite are not uncommon within and on the surface of the sphalerite. They appear to be associated with the dark-colored zones and may occur within the zone or at the upper edge of it. That they are essentially contemporaneous with the sphalerite and not

EXPLANATION OF PLATE 5

Photographs of ore specimens.

- A.—Typical ore specimen showing crustification and banding characteristic of open-space filling. This specimen represents half of a complete vein and shows, from bottom to top, sphalerite, marcasite (thin layer on sphalerite), and rhombohedral calcite. Fragments of early pyrite layer can be seen at bottom of specimen. Wall rock is missing. Natural size.
- B.—Photograph of thin section of sphalerite showing typical light-dark-light sequence of color banding. Bottom of picture is next to vein wall. Magnification 4×.
- C.—Sphalerite on dolomite, Smith No. 2 mine, showing several repetitions of intermediate dark reddish brown bands. Galena is barely visible as lighter gray in dark sphalerite and as dark gray island in late light-colored sphalerite. Crack between sphalerite and wall is due to partial oxidation of pyrite. Magnification 2×.



a replacement is shown by the fact that their lower contacts with the sphalerite, or those toward the wall, are controlled by sphalerite crystal faces, but the upper contacts are smooth and spherical as if the pyrite had grown into an open space and was later covered by sphalerite (pl. 6A).

The main part of galena deposition followed the bulk of the sphalerite deposition with only a small amount of overlap early in the galena stage. The large massive aggregates of galena, which characterize the shallow deposits, appear to be free of sphalerite. Spots within the deposits, however, where deposition of galena was light and of relatively short duration, may show tiny crystals or aggregates of sphalerite on the surfaces of small (one-fourth of an inch) galena cubes and groups of cubes that in turn lie on massive sphalerite. A specimen from the Smith No. 1 mine showed a porous aggregate of sphalerite and galena crystals, of apparently contemporaneous growth, attached to the surface of a normal massive sheet of sphalerite containing the light-dark-light sequence of color banding.

Galena of an earlier stage is found at some places as intergrowths in the massive sphalerite. The galena occurs in arborescent and fibrous aggregates whose long dimension is parallel to the blades of sphalerite. Contacts of galena with sphalerite (pl. 6B) generally show control by sphalerite crystal faces at the base of the galena aggregates, curving mutual boundaries along the sides, and galena crystal faces at the upper ends, indicating contemporaneous growth into an open space.

Galena apparently had an affinity for the darker sphalerite. Within the banded sphalerite the galena occurs chiefly in the dark red bands. The sphalerite that overlaps into the main galena stage is amber or orange to red-orange instead of the light honey-yellow characteristic of late sphalerite.

Late marcasite, which may coat sphalerite and galena in the deeper zinc deposits, was not found in the ores of the crevice deposits. As the crevice deposits are largely oxidized, however, it cannot be assumed

that late marcasite was never present in the shallow lead-zinc orebodies.

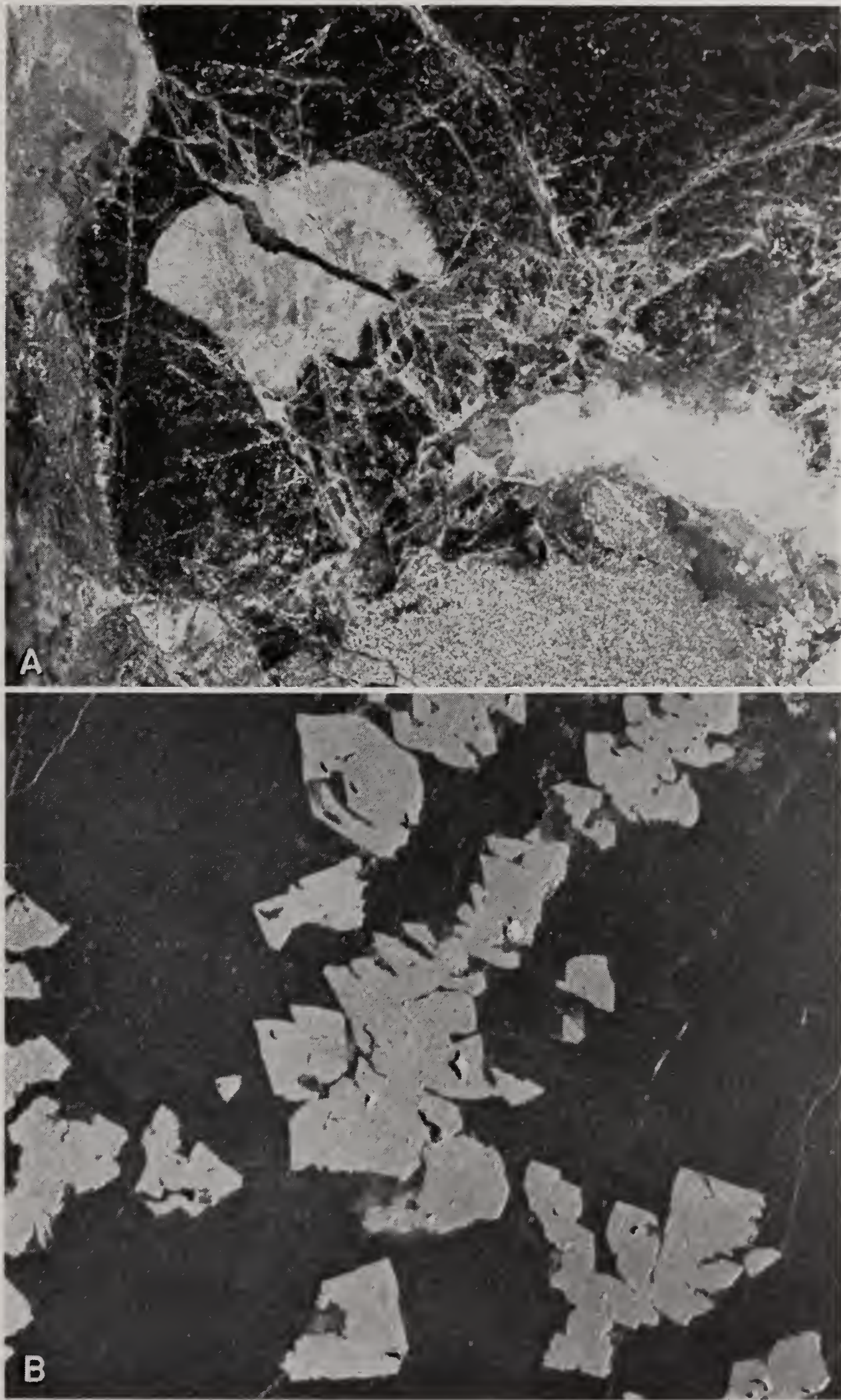
Calcite, as was previously mentioned, is rare in the crevice deposits. In one mine, calcite was found occupying the central part of a galena vein. It was therefore presumed to be younger than the galena, as is the calcite of the deeper zinc orebodies.

TIME OF MINERALIZATION

The time of mineralization, based on direct evidence, is post-Silurian, pre-Pleistocene. The Silurian Dolomite, the youngest of the rocks in the lead-zinc district, contains a few small scattered masses of galena in crevices, and bones of mastodons have been found in the clay fill of the crevices in the Galena Dolomite (H. B. Willman, personal communication) indicating that the deposits were in place by Pleistocene time.

By less direct evidence, the mineralization can be dated as post-Pennsylvanian. Evidence from the Illinois Basin (Weller and Bell, 1937) suggests that the greatest deformation in the Upper and Middle Mississippi Valley regions came during the Appalachian revolution. As the synclines trending northeastward are the most prominent structural features of the lead-zinc district, it is reasonable to assume that they are Appalachian in age, and that the orebodies related to them are no older than that. If the Appalachian folding had merely accentuated pre-existing ore-bearing structures, there should be considerable post-ore brecciation within the orebodies, but the only evidence of post-ore brecciation consists of minor occurrences in the lower part of flat-and-pitch orebodies. Such occurrences probably are caused by continued leaching in the Guttenberg and Quimbys Mill Limestones and accompanying sagging of the overlying beds (Willman, 1945).

A possible Cretaceous age for mineralization in the Mississippi Valley region has been suggested on the basis of a Cretaceous dating of basic igneous dikes in Kentucky and Arkansas (Bastin and Behre, 1939). Assigning this age to the Upper Mississippi



EXPLANATION OF PLATE 6

Photographs of ore specimens.

- A.—Photograph of portion of sphalerite vein showing paragenetic relations of globule of microcrystalline pyrite to surrounding sphalerite. Sphalerite is dark, pyrite is speckled gray, calcite is light gray. Pyrite at bottom of photo is next to vein wall. Magnification 5 $\times$.
- B.—Photograph of polished section of ore, Smith No. 1 mine, showing relations of arborescent galena to enclosing sphalerite. Magnification 4.5 $\times$.

Valley deposits involves so many assumptions, however, that the idea must be considered no better than a possibility.

DEPTH OF MINERALIZATION

The depth at which the host rocks were buried when the crevice deposits were formed cannot be accurately determined but the Galena Dolomite probably was covered by the Maquoketa Shale and Silurian Dolomite, aggregating about 500 feet in thickness, and, perhaps, by Pennsylvanian rocks of unknown thickness.

Students of the Pennsylvanian differ in their opinions as to the actual thickness of Pennsylvanian sediments deposited in northwestern Illinois but generally agree that it was not very great. As an upper limit, 1000 feet probably would be a reasonable figure to use for purposes of discussion.

If the mineralization occurred at the time of the Appalachian revolution, the depth to the Galena would have been about 1500 feet. If the deposits were emplaced in Tertiary time after the formation of the Dodgeville peneplain (accordant Silurian summits), the depth would have been only about 500 feet because the Pennsylvanian strata would have been removed. There is no definite basis for a choice between these two depths, but it is apparent, whatever the choice, that the ore was deposited at a relatively shallow depth.

ORIGIN OF THE CREVICE DEPOSITS

SOURCE OF THE MINERALIZING SOLUTIONS

Current investigations of the zinc and lead deposits of northwestern Illinois suggest that the paragenesis of both shallow lead-zinc deposits and the deeper zinc-lead deposits are the same and that they had a common origin. Therefore, the following discussion of the origin of the shallow deposits applies also to the deeper deposits, in at least its broader aspects.

The Upper Mississippi Valley lead and zinc district, which includes the deposits in Illinois, Wisconsin, and Iowa, has been a mining area for many years and has been

the subject of geological studies since the early part of the 19th century when Owen (1840) reported on his 1839 survey of the district. Percival (1855), one of the first geologists to consider the question of origin, thought the ores were emplaced by hydrothermal solutions rising from a deep-seated magmatic source. At about the same time Whitney (1854) subsequently supported by Chamberlin (1882), Van Hise (1900), Bain (1906), and Cox (1914), advanced the theory that the ore was derived from the surrounding rocks (lateral secretion) and concentrated into the present deposits by descending groundwater. Later, additional data (Newhouse, 1932, 1933; Graton and Harcourt, 1935; Bastin and Behre, 1939) brought the hydrothermal theory into favor again.

Recently, data from the study of sulfur isotope ratios in the Upper Mississippi Valley ores have again raised some questions regarding the magmatic origin of the ore-depositing solutions. Kulp and others (1956) conclude that the isotope ratios indicate a sedimentary sulfate source for the sulfur. As the science of isotope geology is still young, however, such evidence cannot be fully evaluated until more is known about the behavior of isotopes in various physical and chemical environments.

Present knowledge, not including the difficultly evaluated isotope data, is not weighted heavily in favor of either the magmatic or the lateral secretion hypothesis. The old descending meteoric water version of the lateral secretion theory has been generally discarded for three reasons: 1) ore deposits have been found under the relatively impervious Maquoketa Shale; 2) work with fluid inclusions in sphalerite (Newhouse, 1933; Bailey and Cameron, 1951) has indicated ore deposition temperatures of around 100° C.; 3) a fluid inclusion in galena from northwestern Illinois was analyzed by Newhouse (1932) and found to contain a high percentage of NaCl. Another version of the lateral secretion theory, however, the artesian theory presented by Siebenthal (1915) for the Tri-State (Missouri-Oklahoma-Kansas) district, cannot be as easily discounted.

In spite of all the uncertainties, probably the majority of ore geologists would classify the Upper Mississippi Valley deposits as hydrothermal with a magma as the source of the metals and heat.

FORMATION OF THE DEPOSITS

It has been pointed out that the crevice deposits were formed along vertical joint-like fractures at favorable stratigraphic horizons by the filling of open spaces. In some instances, the open spaces were clearly the result of brecciation. Solution of the dolomite rock appears to have been the important factor in forming open fissures, although the solution of the dolomite may have been abetted at many places by intense fracturing of the rock.

The localization of the mineralized horizons in rather narrow vertical limits is probably due to differing physical properties of the host rock. Where solution of the dolomite was apparently the chief factor in forming the open spaces, the rock is probably more porous than adjacent layers. Where brecciation is responsible for the crevices, the rock is apparently more brittle than beds above and below it. The movement that produced the breccia must have been horizontal, as no evidence of vertical displacement of strata has been observed along the crevices. The fact that strike-slip faults have been found in the district (Heyl et al., 1955) makes such an explanation feasible.

That the open spaces existed before deposition of ore began is evident because the ore minerals, beginning with early pyrite, line the open fissures and pockets. The identity of the solutions that made the open spaces, however, remains a matter of conjecture. They may have been a pre-ore phase of warm ascending solutions, or they may have been ordinary groundwater. If the theory of precipitation of the ore minerals by mingling of the ore-bearing solutions with groundwater, as presented in the following paragraphs, is correct, then it is possible that the open spaces also were formed by groundwater.

The solutions that deposited the metallic sulfides appear to have been warm

ascending solutions. Not much is known of their composition or of the manner in which the metals were transported. Newhouse (1932) tested the composition of a fluid inclusion from a galena crystal from the Illinois-Wisconsin district and found that it was a concentrated chloride solution with Na and Ca as the dominant cations. Subsequently, Garrels (1941) showed that lead can be carried in solution in the form of chloride ion complexes and will be precipitated upon dilution of the chloride ion concentration. Zinc and iron, however, do not form complexes with chloride, and tend to precipitate as sulfides out of a chloride solution before the lead does. Garrels' findings help explain the occurrence of galena as a late mineral in the Illinois-Wisconsin deposits.

To explain the manner of transport of the zinc and iron is more of a problem. Although various types of solutions have been suggested, none has been regarded as completely satisfactory. However, because of the fact that the deposits occur in carbonate rocks, it is in general felt that neutralization of acid solutions played a part in the precipitation of the Zn and Fe sulfides.

If, as proposed by Garrels (1941), dilution by groundwater caused precipitation of lead sulfide, it may be presumed that groundwater also caused neutralization of the solutions and the subsequent precipitation of the iron and zinc sulfides. Groundwater in carbonate rocks such as are present in the Illinois-Wisconsin district can be expected to be relatively rich in bicarbonate ions. Lowering of temperature as the rising solutions neared the surface and lowering of pressure as the solutions entered the fractured and cavernous ground also could have played a part in causing precipitation of the sulfides.

In summary, the formation of the crevice lead-zinc deposits may have involved these events: 1) a period or periods of diastrophism that fractured the rocks; 2) a period or periods of erosion during which groundwater dissolved the carbonate rocks along joints and in brecciated zones, thus de-

veloping open joints, caverns, and honey-combed rock; 3) influx of warm solutions from depth into the zones of lower pressure caused by the fracturing and groundwater solution; and 4) precipitation of the sulfides when the ore-bearing solutions mingled with groundwater in the breccia zones and open joints.

CREVICE MINING METHODS

The following summary of early mining methods is taken chiefly from Shaw (1873) and from observations in old workings during the present study. Much the same information is also contained in Calvin and Bain (1900).

Early mining and exploration methods consisted largely of digging pits to the surface of the bedrock in search of an ore-bearing crevice. If residual lead ore was found at the surface of the bedrock, the strike of the deposit was followed, and the waste dirt was thrown into the excavated space behind the miner. In this way were developed the lines of closely spaced pits now seen in old areas of diggings. In an area of closely spaced crevices where residual galena was in "patch" deposits, almost the entire surface covering was excavated, leaving only mounds and pits. Parts of the areas shown in plate 2 present such an aspect.

If the prospect pit struck the "soft ground" of an open crevice when bedrock was reached, the excavation followed the crevice downward to ore or the water table. If ore was encountered, a drift was driven along the crevice to excavate the ore. Because the ore was concentrated in vertically limited zones, most of the mines consisted of drifts along those horizons and had a minimum of stoping. Judging from the close spacing of shafts (pl. 2), drifting underground was of only limited extent in some areas, presumably where the ore was at very shallow depths.

If a crevice were found in a bluff or at the base of a hill, an adit was driven along it. Shaw (1873) mentions driving adits "so as to prospect all the parallel ranges in a hill or group of diggings by one level,"

but no evidence of this was found during the present study.

Most of the excavating in a mine was done by pick and shovel, but all the older reports mention the use of blasting powder in limited amounts. The ore was transported to the shaft or adit entrance by hand, wheelbarrow, or in cars on wooden rails. Hoisting was done by hand windlasses. If water was encountered, mining was stopped unless a pump was available and the deposit was deemed large enough to warrant the added expense of pumping. Water in an adit mine was sometimes removed by means of a wooden trough that sloped from the face of the mine back to the entrance. The water at the working face was poured into the trough by hand.

The operations were typically small, involving only a few men associated as partners, although in more recent times some mines were operated by regular companies that hired miners by the day. The narrow working space allowed by the shape of most deposits generally allowed only two men to work at the ore face at one time.

The ore was cleaned at the mine and taken by team to a local smelter. The resulting pigs of lead were teamed to Galena and there transferred to steamboats for shipment down the Galena River to the Mississippi and thence to St. Louis for sale.

Since 1920 lead mining has been so limited that little has been done to improve the old mining methods. The use of churn drills to explore extensions of known crevices and ranges has made prospecting more efficient, but underground methods remain essentially the same. Loading and tramming are still done by hand, although hoisting is now mechanized.

Efficient pumps are now available and are used to a limited extent, but mining is still done mainly above the water table where oxidation and weathering have softened the host rock and made the ore amenable to easy digging and hand separation. If mining is carried on in hard, fresh rock, drilling and shooting become necessary and mining costs are raised. In addition, milling costs are incurred and the ore

loses the premium paid for the relatively pure, hand-separated galena, which is approximately 87 percent lead. Mill concentrate is only 80 percent lead.

DESCRIPTION OF MINES

Detailed descriptions of ten typical shallow lead mines follow. In the six mines that were in operation when examined, direct observations could be made on occurrence and distribution of ore. In the four abandoned mines only fragmentary evidence on ore was available, and information had to be deduced from a study of the size and arrangements of the workings.

Other prospects and abandoned mines examined in reconnaissance fashion by the writer and other members of the Illinois State Geological Survey staff are summarized in table 1, which also includes data from the older reports (Bain, 1906; Cox, 1914) on mines now inaccessible or forgotten. Exact locations of some of the older mines are not known despite efforts of Survey staff members, particularly H. B. Willman and R. R. Reynolds, to check them in the field.

ACTIVE MINES EXAMINED

Herman Smith Mine No. 1

The Herman Smith No. 1, operated until recently by Hickory Hill Mining Company, is in the NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 1, T. 28 N., R. 1 W. The deposit was essentially a coarse breccia ore of zinc with subordinate galena (fig. 6) in a 10- to 15-foot wide zone of closely spaced subparallel crevices. Where the roof was flat and not pitted and irregular from solution of the dolomite host rock, at least two or three crevices striking about N. 85° W. could be discerned.

The abandoned workings extend roughly 1000 feet in a N. 85° W. direction. They were entered by an inclined adit at the east end and by a 100-foot shaft about 500 feet west from the adit. The deposit was generally about 10 feet wide and 5 feet high. The cave above the ore-bearing zone was typically about 5 feet high, and the height of the workings from the top of the

natural cave to the floor of the mine generally was 20 to 25 feet. Locally the workings are 50 or more feet high where solution of the dolomite has carved a cave for some 30 feet above the ore deposit.

The orebody occurs in the upper part of the Prosser Member. Drill holes encountered the top of the deposit 40 to 50 feet above the "Drab" (the cherty portion of the Prosser), or essentially at the base of the Stewartville Member. The presence of a few *Receptaculites* in a limited exposure of dolomite above the adit entrance confirms the position, as this fossil in some abundance marks the basal portion of the Stewartville.

The main part of the deposit consisted of veins of various attitudes in a zone of broken dolomite that appeared to be sharply limited along each side by a vertical crevice. In places the bounding crevices were zones of closely spaced parallel fractures about one-half to 1 inch apart. These outside crevices, whether a single fracture or a zone of parallel fractures, carried in most places narrow veins of sphalerite, one-quarter to 1 inch wide. Below the coarse breccia, honeycombed rock appeared to follow a specific bed for the extent of the orebody. In places, the extremely vuggy rock carried enough sphalerite to be considered ore; elsewhere it was mineralized only with pyrite and marcasite that impregnated the rock and lined the vugs. The honeycomb part of the deposit was not limited by the bounding crevices but continued unchanged into the walls an unknown distance. There was no evidence of faulting in the deposit, but solution of the dolomite along fracture planes would have destroyed telltale slickensides. Also, the massiveness of the beds made it difficult to detect any vertical component of movement.

Some galena occurred in the central part of the sphalerite veins, and a minor amount was found intergrown with the sphalerite. No galena was encountered in the honeycomb ore. Loose pieces of galena, 3 inches across on the average, were found locally in the clay and dolomite

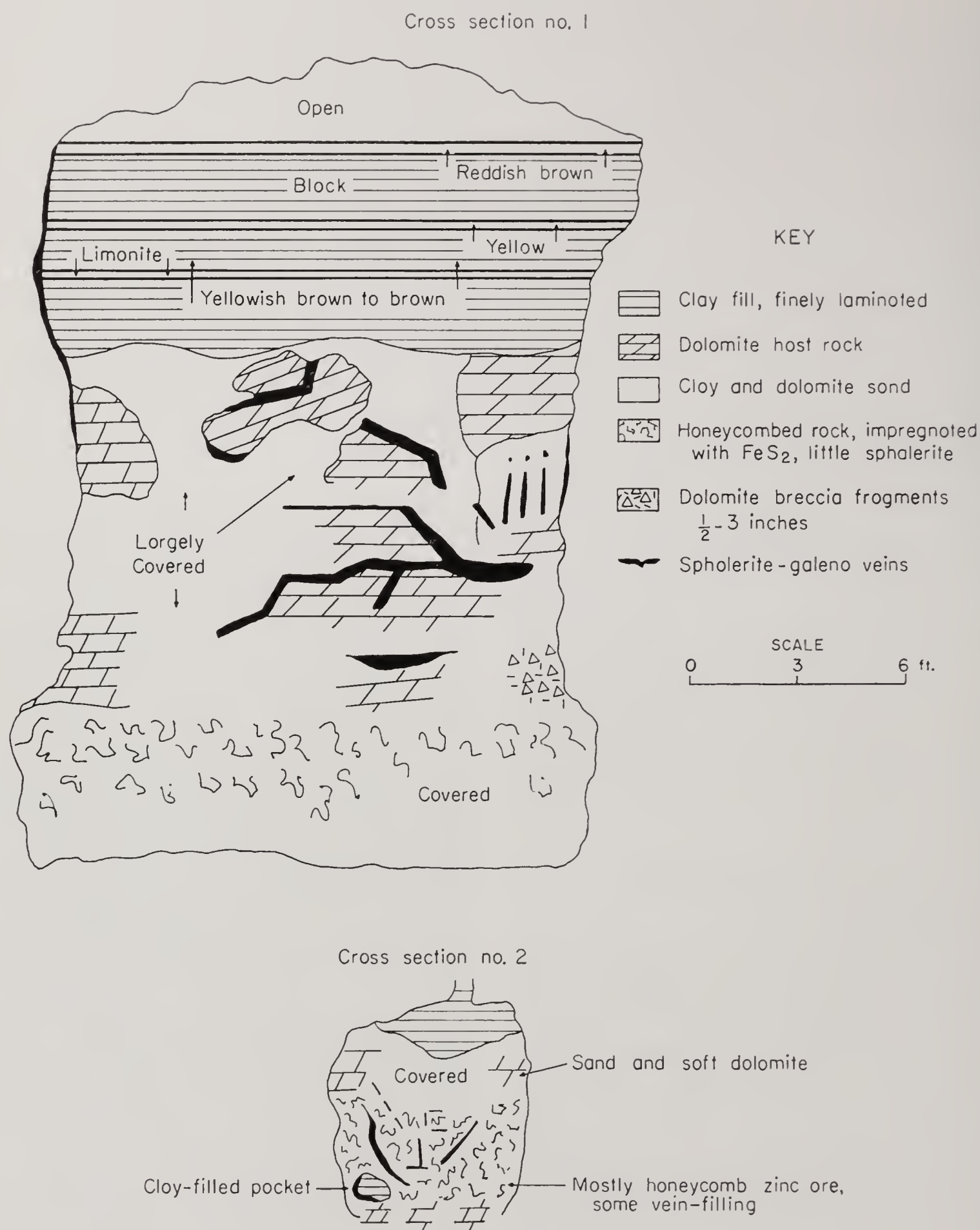


FIG. 6.—Cross sections of Herman Smith mine No. 1. Section 1 is sketch of working face showing laminated clay fill, coarse breccia ore, and honeycombed rock mineralized with iron sulfide. Below the laminated clay the material grades downward from dolomite sand, clay, and weathered dolomite “boulders” to fresh dolomite. Slumping clay and dolomite sand hide much of the detail of the working face. Note local area of finer breccia at lower right. Section 2 is sketch of working face 500 feet west of section 1. This face is approximately 15 feet lower in elevation than that of section 1, and the honeycombed rock is probably the same stratigraphic horizon in both faces. Note that here it is zinc ore.

sand mixture of the upper part of the deposit beneath the laminated clay fill. The size of the loose galena pieces indicates that open spaces existed in the now disintegrated upper part of the deposit that were larger than the 1- to 2-inch veins of sphalerite and galena still in place in the lower part of the deposit. It may be that the clay-filled cave that overlies the ore existed in very nearly its present form at the time of ore deposition and that the loose pieces of galena were at one time attached to its walls. A small part of the deposit that had not suffered disintegration contained just such a mineral-lined cave, about 1 foot high and 5 feet wide, above the coarse breccia ore, suggesting that the major part of the deposit may have had a similar configuration.

Herman Smith Mine No. 2

The Herman Smith No. 2 deposit is in the SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 36, T. 29 N., R. 1 W., half a mile north of the Smith No. 1 mine. It is on the westward extension of the old Hoosier zinc mine and is similar in structure to the Smith No. 1 deposit, and apparently, to the Hoosier deposit (Cox, 1914). The production from the mine, however, has been chiefly galena, whereas the Smith No. 1 contained only subordinate galena, and the Hoosier apparently contained little or none (Cox, 1914). Like the Smith No. 1, the Smith No. 2 deposit lies along a fracture zone controlled by closely spaced parallel crevices trending N. 85° W. Entrance to the mine is gained by an inclined adit at the east end.

Sphalerite occurs throughout the Smith No. 2 mine in a breccia ore, generally of lower grade than in Smith No. 1, and, in many places, grades into a fissure-filling deposit with only a few vertical and inclined veins. The eastern portion of Smith No. 2 was like the No. 1 deposit, a breccia ore of zinc with subordinate galena, but a few hundred feet west of the entrance of the inclined adit a cave lined with a thick sheet of galena was encountered. This is the deposit that was described earlier as an example of a crystal-lined cave deposit.

Figure 7 shows the various stages of partial disintegration of the cave lining through weathering and also shows the relations between the various types of ore.

No stratigraphic markers were seen in the Smith No. 2 mine. Drilling records show that the eastern portion of the orebody is in the same stratigraphic interval as was the Hoosier (Cox, 1914), that is, between the upper bentonite (18 feet above the "Drab") and the base of the Stewartville (45 feet above the "Drab"). A few hundred feet to the west where the galena-lined cave was encountered, the top of the ore rose and subsequently reached a maximum of 15 feet above the top of the ore in the eastern portion. Where last examined, the top of the orebody was plunging downward again to the west.

The workings are at present close to 1000 feet long and have an average trend of N. 85° W. Where last examined, the heading did not show the characteristics of a crystal-lined cave, and only further mining will determine whether this area is just another interruption in the rich galena-lined cave or the end of it. Ore in the face contained pieces of galena, some as large as 1 foot across, but the face was too disintegrated to determine whether the galena masses had fallen from the walls and roof or had grown in place.

Hartwig Mine

The Hartwig mine, operated by Hickory Hill Mining Company, is near the center of S $\frac{1}{2}$ NW $\frac{1}{4}$ sec. 1, T. 28 N., R. 1 W. The mine produces galena from a 50-foot wide zone of closely spaced parallel crevices trending about N. 85° W.

The workings consist of drifts east and west from a shaft, along what seems to be the north side of the 50-foot wide zone. According to the miners, the drift west from the shaft was barren for the 200 feet that they excavated. A short distance east of the shaft a sizeable pocket of galena was encountered (not seen by the writer). About 125 feet east of the shaft, the drift jogs south 50 feet and cuts across the crevice zone to the south side, from which

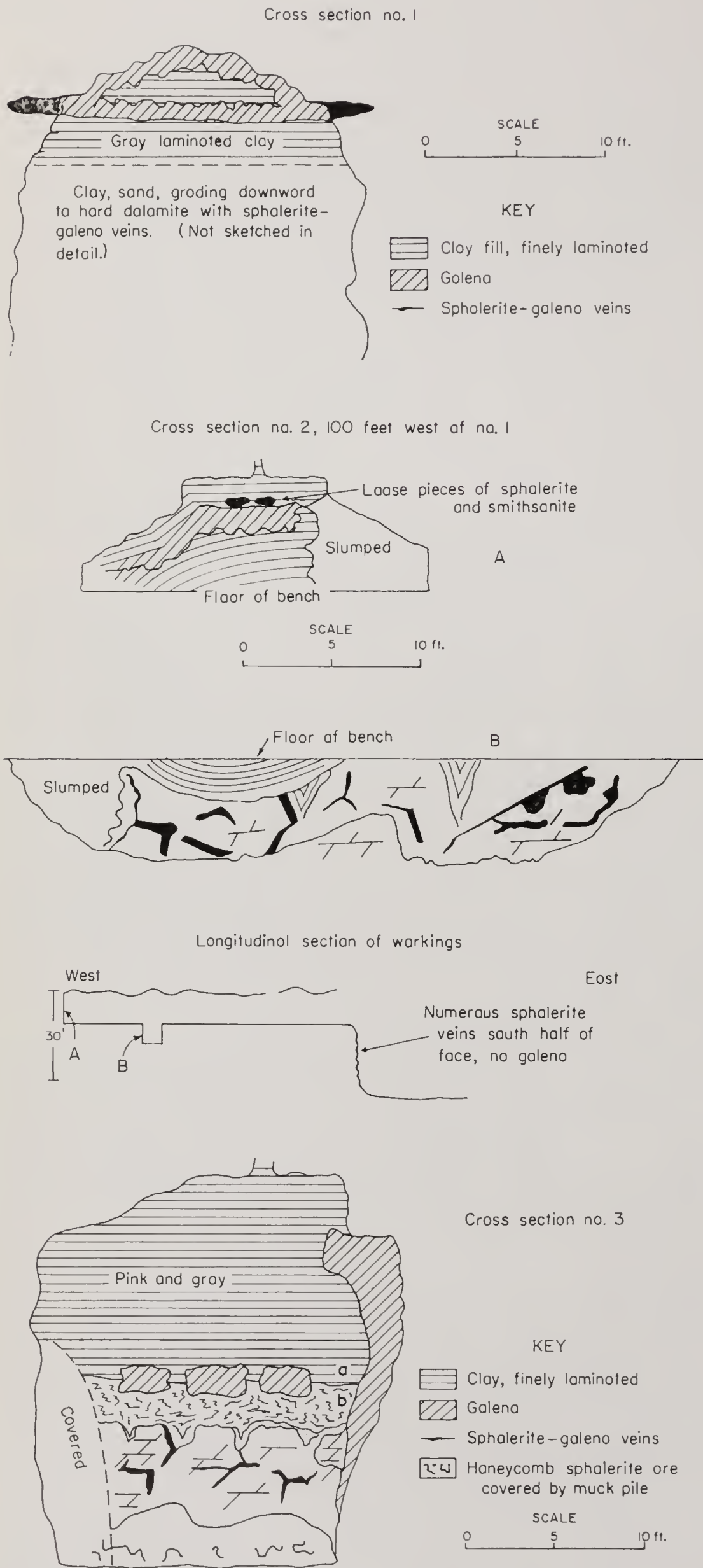


FIG. 7.—Cross sections of Herman Smith mine No. 2. Section 1 is sketch of a working face showing the cave lining of coarse galena. Sketch A under section 2 shows the working face at heading; sketch B shows west wall of trench, 5 feet back from heading. Longitudinal section shows the relations of sketches A and B. This series of sections illustrates the partial disintegration of the original cave deposit, the vertical change from crystal-lined cave downward to coarse breccia, and the apparent gradation from galena above to sphalerite below. The loose pieces of sphalerite, some with galena attached, lying on top of the galena shell, probably came from the central fissure. Slumping clay and dolomite sand mask much of the detail. Section 3 is sketch of working face 200 feet west of section 2. Here the cave lining is further disintegrated. "Clays" *a* and *b* are chiefly laminated, brown to dark brown limonite, with thin streaks and lenses of brownish gray to grayish brown clay and buff-colored dolomite sand. The bedding of horizon *a* is undisturbed but that of horizon *b* is broken up and contorted by the impact of the fallen galena masses. Note the downward change from coarse breccia to honeycomb ore and the disappearance of galena. Slumping clay and dolomite sand mask much of the detail.

point it again turns eastward. A concentration of galena was encountered 100 feet east of the turn and when last examined had been mined for 130 feet.

The mine is not sufficiently well developed to present a complete picture of the distribution of the ore. The rock across the entire 50-foot zone of closely spaced crevices, as seen in the cross cut, is softened and limonite-stained. Widely scattered small pieces of galena, half an inch or less across, can be found along the wall of the cross cut. Only the two bodies of ore mentioned above have been encountered, but the interior of the zone has not been tested except for the one cross cut.

The ore, as seen in the south drift, consists of masses of galena, 6 inches to 1 foot across, in softened and disaggregated dolomite. The working face when last seen was about 15 feet wide and 8 feet high, ending upward in a flat roof. Some distance back from the face the deposit had been 20 feet or more wide. The galena occurred chiefly in the lower two-thirds of the face, but the remaining third was composed of the same soft dolomite rock and dolomite sand. No cave-like opening or clay-filled cavern existed as in most crevice orebodies. Details of the structure were difficult to see in the face because of the soft, loose structure of the materials, but, where seen, bedding planes appeared to be horizontal, indicating that the ore is essentially in place as it was deposited. The galena masses showed rude alignments with bedding planes and with vertical crevices.

The absence of fissure-filling and the unusual width of the occurrence (up to 20 feet) indicate that no single crevice or narrowly limited group of crevices was a favored channelway for either the carbonate-dissolving or ore-depositing solutions. As a matter of fact, the bedding planes appear to have exerted as much control over the localization of the individual masses as did the vertical crevices.

The type of occurrence, isolated masses rather than veins or cavity linings, suggests that the galena may have been de-

posited by replacement rather than by open-space filling. Because of the extensive oxidation and weathering of the deposit, no direct evidence of either replacement or open-space fillings now remains. Evidence from an unoxidized portion of the Dooling deposit, described below, however, shows that this type of occurrence can be due to open-space filling.

Dooling Mine

The Dooling mine, also operated by Hickory Hill Mining Company, is in the NW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 1, T. 28 N., R. 1 W., about half a mile east of the Hartwig mine. It is essentially a single crevice deposit, but the galena occurs in isolated masses like the deposit in the Hartwig. No evidence of zinc mineralization was seen.

The shaft is reportedly 118 feet deep and intersects old workings about 25 feet above the bottom. At the lowest level the present miners encountered, a few feet south of the shaft, a body of ore with a N. 80° W. trend. None of the old workings appear to lie directly over this occurrence. What was apparently the main crevice in the old mine lies farther south, about 35 feet from the shaft and 25 feet above the present lowest level. The old drift extends east-west along this crevice about 500 feet. A drift is being driven along the same crevice about 15 feet below the old workings. Close to the point where the cross cut from the shaft intersects the main crevice, the crevice splits, with one branch continuing east and the other trending N. 85° E. Both branches are mineralized, but the east-trending branch appears to contain a little more galena.

The ore occurs in individual masses one-half inch to 4 or more inches across. In the main crevice the larger masses are arranged in a vertical line and apparently occur along a specific fracture. There is no vein-like fissure-filling, however, and between the galena masses the crevice is tightly closed. In the roof the crevice likewise is tight and can be traced only by a line of small solution cavities along it. Alongside the large centrally arranged ga-

lena masses are smaller pieces of galena, some of which are irregular and branching. At this level oxidation and weathering have been only moderate, and it is necessary to use explosives in driving the drifts.

The body of ore on the lowest level just south of the shaft had been mined out when I first visited the mine, but from the miners' descriptions it was similar to the ore in the Hartwig mine. It was reported to consist of large chunks of galena in soft dolomite and dolomite sand. Still visible at the west end, however, were nodules of galena rimmed with pyrite and arranged along bedding planes in the dolomite. No crevices could be recognized in the face. The dolomite was much fractured and contained many pyrite veinlets, but there was no sign of rotation or other displacement of individual dolomite fragments. Although the distribution of the nodules suggests replacement rather than open-space filling, the rim of pyrite around each one indicates the latter. As pyrite is the first sulfide to be deposited, the cavities must have been present before sulfide deposition began.

Little Giant Mines

The Little Giant mines, operated during the late 1940's by the Little Giant Mining Company, are in the N $\frac{1}{2}$ S $\frac{1}{2}$ fractional sec. 32, T. 29 N., R. 1 E. The orebodies overlie and extend west from the south end of the N. 10° W.-trending Graham-Ginte flat-and-pitch zinc deposit, from which they are separated by barren rock. It is reported that the main mine has been operated intermittently by others since the Little Giant Mining Company ceased operations.

The main workings (fig. 8) are 30 feet wide and were about 265 feet long when mapped. The shaft is 101.5 feet deep from the collar to the track level. Height of the orebody is generally 10 to 12 feet.

The stratigraphic positions of deposits 1 and 2 appear to be the same, judging from shaft depths and collar elevations. The bottom of shaft No. 2 is about 12 feet below the top of the "Drab."

The main deposit was chiefly a honeycomb ore of zinc and lead with zinc pre-

dominating about 3 to 1. The two N. 85° W. crevices that controlled the deposit (fig. 8) contained occasional pods of galena cubes in locally widened portions. In one pod the cubes measured 6 inches on an edge and appeared to be lying unattached in the bottom of the open space. Inclined galena and sphalerite-galena veins at some places crossed the deposit (fig. 8).

Shaft No. 2, 99 feet deep, was sunk on an approximately parallel crevice, trending N. 80° W., to develop rich galena mineralization encountered in a churn drill hole. A cave at the east end of the workings as mapped contained a considerable tonnage of galena in 6- to 8-inch and smaller cubes. The cave had received none of the laminated clay fill found in the Smith crevices. Loose cubes of galena, lightly covered with clayey dolomite sand, formed the floor of the open space, which was about 8 inches high and 1.5 feet wide. The open space above the ore appeared to be about 10 to 12 feet long by visual estimate.

Downward to the floor of the mine, which was 6 feet below the top of the deposit, the galena became mingled with dolomite sand, blocks of dolomite, and small pockets of wad. The bottom of the deposit had not been reached when I last visited because it was below the water table and no pumping was being done. At the west end of the drift there was no open space but only a weathered honeycombed deposit consisting of cubes of galena up to 1 inch on an edge and knots of dolomite scattered through yellow-stained dolomite sand.

Appleton (Dinsdale) Mine

The Appleton mine (fig. 9) is in the SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 10, T. 28 N., R. 1 E., on the Wilmer Winters property. The mine was dewatered in 1952 by the Turner Construction Company of Boscobel, Wisconsin, for the first time since operations ceased in 1910. The Turner Company drove an adit into the mine from the base of the hill and did some preliminary development work in the deposit but then ceased operations.

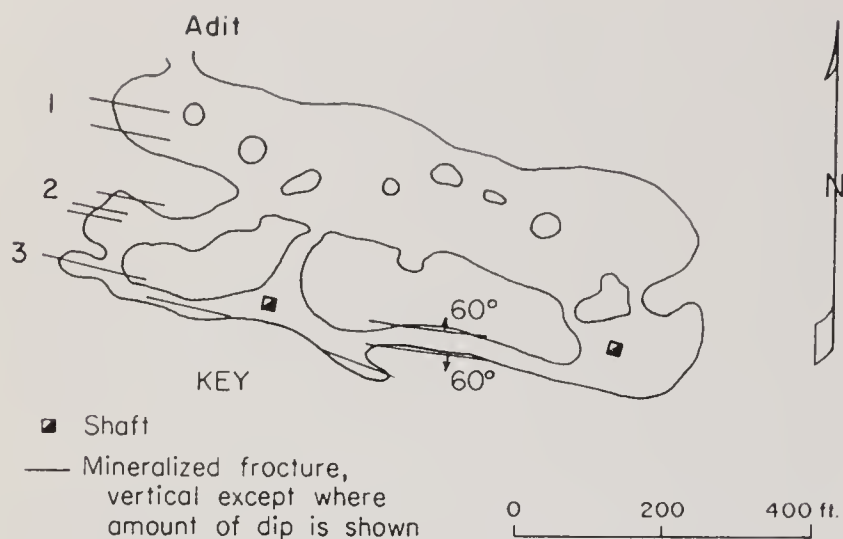


FIG. 9.—Map of Appleton mine showing location of mineralized fractures. Main orebody is controlled by fractures that trend N. 85° W. These are unmineralized as seen in the roof of the mine and therefore are not shown on the map. At locations 1, 2, and 3 sphalerite and galena occur in vertical, inclined, and horizontal veins and in breccia. Map by W. D. McCoy, Turner Construction Company. Geology by J. C. Bradbury, 1953.

The main workings are 80 feet wide and 440 feet long (fig. 9). The height of the mine between an essentially flat roof and floor appeared to be about 10 to 15 feet.

The orebody is a honeycomb deposit of zinc with subordinate lead in the basal part of the Galena Formation, the type of orebody often referred to as a "middle-run" deposit. The top of the Ion Member of the Decorah Formation shows in a development drift at the west end of the main workings, but it is not ore-bearing.

The mineralization follows a zone of fractures that trend N. 80° to 85° W. and that are tightly closed in the roof of the mine and at the east end. At the west end the main crevices become mineralized fissures and are the loci for narrow but fairly rich zones of zinc and lead mineralization that extend an unknown distance west from the main orebody. Within these narrow zones the ore occurs in fissure-fillings and breccia.

In the main part of the orebody the ore minerals, as seen in the walls and pillars in the mine, occur in 1/4- to 1/2-inch aggregates, mostly sphalerite but some galena, in vugs in the dolomite. Higher-grade streaks follow certain beds about 1 foot thick.

ABANDONED MINES EXAMINED

Four abandoned crevice mines were mapped, of which three were in the California Diggings area about five miles south of the city of Galena, and the fourth along Smallpox Creek in the Guilford area, about five miles directly east of Galena. Evidence for mode of occurrence of the mined-out ore ranged from poor in two of the California Diggings mines to good in the Hutchings mine in the Guilford area. The California Diggings area is a concentrated area of essentially east-west mineralized crevices in a stretch of bluffs extending 2 1/2 miles north-south along the Mississippi River. Bain (1906) indicates that the area was active from 1849 to 1855, and Cox (1914) states that mining was carried on in the area largely between the years 1863 and 1865. Only a few of the old adits are accessible.

The three mines in the area that were studied are the Nicholson No. 1 and No. 2 mines and the Little Princess mine.

Nicholson No. 1 and No. 2 Mines

The Nicholson mines (named for the owner of the property at the time of our examination) are near the center of the E 1/2 sec. 21, T. 27 N., R. 1 E. Plate 3 presents a plan map and longitudinal and cross sections of the accessible workings.

The two mines are parallel, trending N. 80° W., and are 850 and 735 feet long, respectively, to the limits of accessibility. As shown in the longitudinal sections, both sets of workings incline gently downward to the east and eventually are closed to further access by the water level. The workings range from 3 to 20 feet wide and from 5 to 12 feet high, not including the winzes.

The main workings are not ruler-straight but follow a set of fractures of generally N. 80° W. but slightly varying strike. Subordinate drifts follow parallel fissures and also branch out along another set of fractures striking close to N. 20° E.

The principal workings in both mines are at approximately the same stratigraphic level. The upper bentonite, 18 feet above

the cherty portion of the Prosser, was recognized in the wall of one of the drifts.

There is little remaining evidence of the types of ore mined from the Nicholson crevices. The only sulfide mineralization found was sporadic galena as scattered cubes and irregular aggregates in calico rock in the walls of the drifts. The calico rock appeared to be confined to certain beds in the walls, but, as viewed in the headings of drifts along subordinate crevices, this type of alteration was general along the crevice. Judging from the widths (up to 20 feet) of the workings in places, honeycomb ore, from which calico rock develops on weathering, may have been an important part of the orebody. No evidence of fissure-filling was found, but it is not unlikely that some did occur.

No evidence of zinc mineralization was encountered, either as sulfide or carbonate. It is reported that the only zinc produced in the California Diggings area was from the Royal Princess mine, which has been described by Bain (1906) and Cox (1914).

Little Princess Mine

The Little Princess mine is near the south line of sec. 21, T. 27 N., R. 1 E., south of the Gill mine (pl. 1). The accessible workings are shown on plate 4 in plan view and longitudinal and cross sections. The main drift is 900 feet long as surveyed and continues an unknown distance beyond the point where water prevents further access. The workings are narrow, from 2 to 8 feet wide. The height ranges from 4 to 7 feet except locally where "chimneys" extend 20 feet or so above the main level and 15 feet below. A lower drift whose floor is 15 feet below the main level is broken into at several places.

The Little Princess workings present a somewhat more complicated pattern than those on the Nicholson property. The ore apparently followed a series of connected sub-parallel crevices that trend N. 80°-85° W., and, to a much lesser extent, another set trending N. 20° E.

The stratigraphic position of the upper workings is the basal part of the Stewart-

ville, identified by abundant *Receptaculites* throughout much of the accessible workings. As the vertical distance from the top of the upper level to the floor of the lower level is only about 20 feet, the Little Princess mine can be considered as in a single mineralized stratigraphic zone.

There is more evidence in the Little Princess than in the Nicholson mines of the type of ore mined. Weathered honeycomb galena ore shows in the walls, in the "arch" between the upper and lower workings, and in one of the "chimneys" that extend above the roof of the upper level. Evidence for brecciation in the formation of the honeycomb ore of this mine shows clearly both in the arch and in the chimney. In the arch, as viewed from a rock pile in one of the connecting holes between the upper and lower levels (pl. 4), galena-bearing calico rock in the central part grades outward to sheared zones that contain limonite veins and some galena. In the chimney many of the fragments of dolomite in the calico rock have an angular aspect even though they now are partly disintegrated to buff-colored dolomite sand. In addition, the galena, which is embedded in the reddish brown sand matrix of the calico rock, occurs in irregular, branching aggregates rather than cubes and suggests deposition in a true breccia rather than in vugs.

The only fissure-fillings seen were veinlets of galena in horizontal and vertical cracks along the walls. Possibly the central fracture carried a vein deposit, as in the Little Giant, or the entire deposit may have been breccia ore as in the western part of Smith No. 1.

No evidence of zinc mineralization was noted.

Hutchings (Old Schultz) Mine

The Hutchings (Old Schultz) mine is located very near the center of the E1/2 sec. 19, T. 28 N., R. 2 E., on the L. G. Hutchings property. The workings are somewhat more recent than those studied in the California Diggings area, and some equipment still remains on the surface.

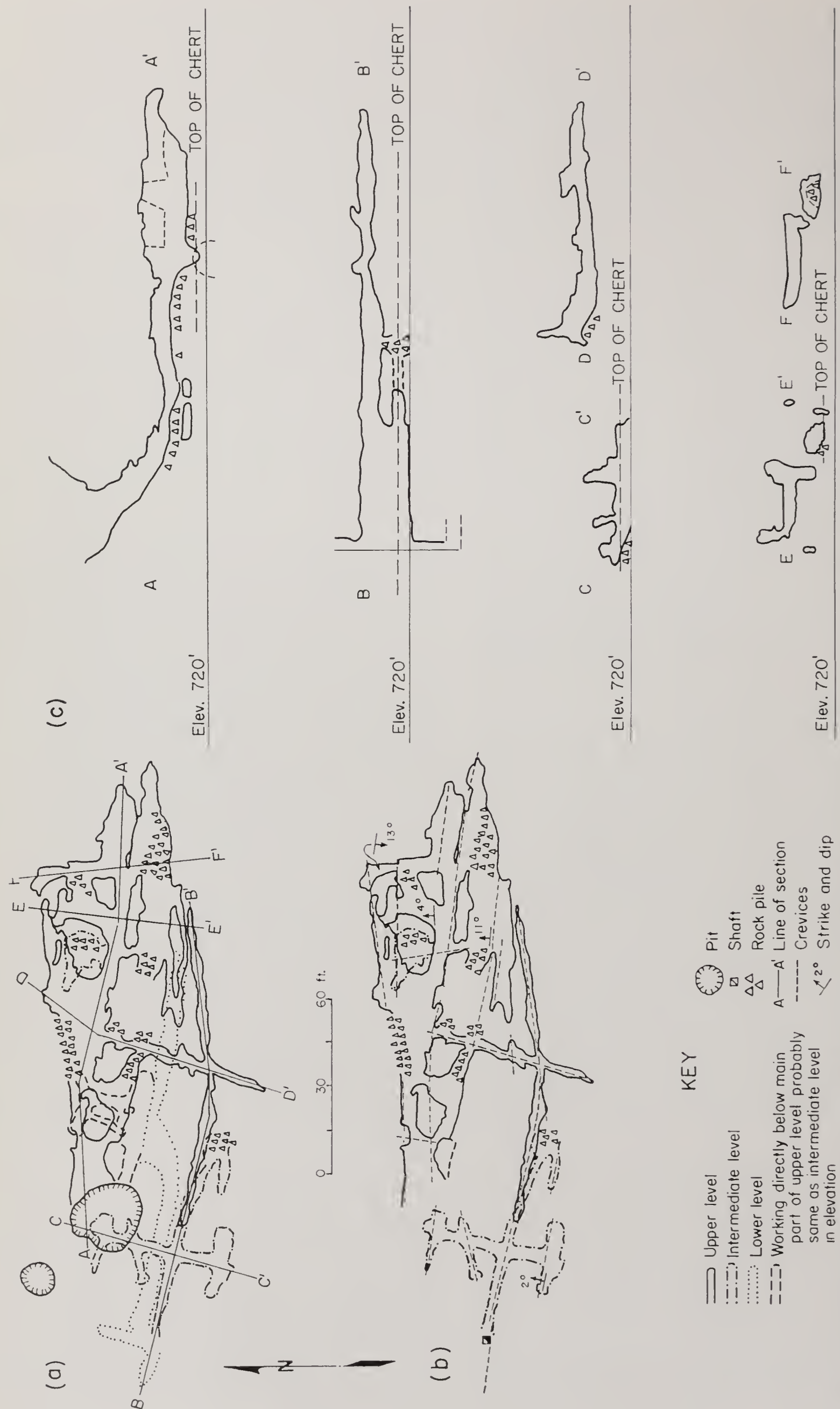


FIG. 10.—Map and sections, Hutchings mine. (a) Upper map is a plan view of the workings and shows the locations of the sections in figures 10c. (b) Lower map shows the crevices. (c) Longitudinal and cross sections of the workings. Map by J. C. Bradbury. Geology by R. M. Grogan, 1947.

Enough ore remains in place to indicate the type of deposit.

The Hutchings mine (fig. 10) is in a type of crevice deposit that is somewhat different from the others described. The galena occurs not only in vertical fissures but also in flats and inclined fissures resembling pitches. Furthermore, the enclosing dolomite strata dip gently inward from the sides of the deposit in a manner similar to that in the typical flat-and-pitch deposits of the lower part of the ore-bearing section.

The workings are 200 feet long and about 50 feet wide. Mining has been principally on three levels with a vertical range of about 35 feet.

The principal crevice direction is N. 75°-80° W., but another set trending E. to N. 80° E. is also mineralized. The N. 20° E. crevices generally are tight but may contain a thin sheet of galena a fraction of an inch wide. South-dipping shear fractures in the lower workings contained veins of galena. There was no apparent movement along the shear fractures.

The dip of the bedding, northward in most of the mine, changed abruptly to southward across a vertical east-trending crevice in the northeastern part of the mine, as shown by dip symbols on the map (fig. 10) and by the roof of the workings in the two cross sections EE' and FF' (fig. 10). The next cross section west (DD') indicates another sharp change of dip across the N. 80° W. crevice, 15 to 20 feet south of the first-mentioned crevice, at the north end of the long cross cut. Note also the relatively strong dip (11° N.) 35 feet east of the cross cut. The strata in the south end of this cross cut appear to flatten out again across the crevice in the southernmost drift. That the dip is flatter at the south edge of the mine is corroborated by a 2° reading at the south end of the cross cut 65 feet to the west. These relatively sharp changes of dip across vertical fractures suggest sagging of the strata similar to the synclinal sags produced by solutional

thinning of strata in the deeper flat-and-pitch orebodies (Willman, 1945). In this instance there has been no drilling to check the possibility of thinning of underlying beds.

The Hutchings deposit occurs in the upper few feet of the cherty Prosser and in the non-cherty strata above. The main part of the workings is above the chert, but drifts at the lower levels are in the cherty beds. In general, the roof of the mine is about 20 feet above the chert with stopes on the northernmost crevice extending another 10 feet higher.

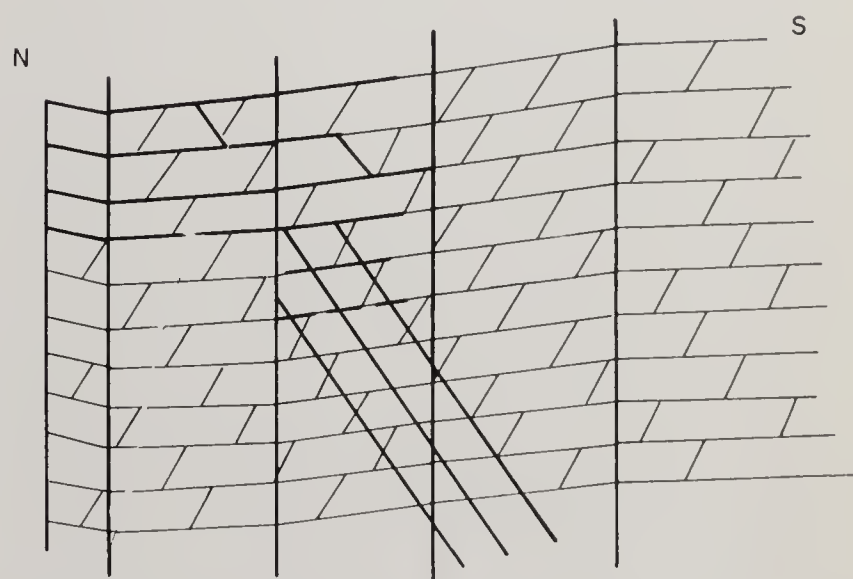


FIG. 11.—Idealized diagram showing relation of ore to structure, Hutchings mine. Heavy lines represent veins of galena.

The ore consists of galena as fissure-fillings in vertical, horizontal, and inclined veins. No evidence of zinc mineralization was encountered. Figure 11, a diagrammatic cross section, illustrates the relations of the various veins to each other and to the structure of the rocks. Such a configuration of veins would be facilitated by the sagging and parting of the rocks as suggested above. The diagram also shows the difference between the Hutchings deposit and the Smith deposits, which also are described as consisting of "horizontal, vertical, and inclined veins." In the Smith orebodies the veins do not form the orderly pattern seen in the Hutchings and are much more closely spaced, suggesting more of a general breaking (brecciation) of the rock.

POSSIBILITIES FOR FUTURE DEVELOPMENT

Possibilities for future commercial production of lead-zinc ores from the shallow deposits in northwestern Illinois depend on many factors—economic, engineering, and geologic. From a geologic point of view, the major consideration is the possibility of finding additional deposits. This involves both the selection of areas where crevice deposits are likely to be found and the selection of the method or methods of prospecting best adapted to the conditions of the area chosen.

SELECTION OF AREAS FOR PROSPECTING

Old Mining Properties

The existence of additional ore in old mining properties is a distinct possibility because of the primitive methods used during the active lead mining period. For instance, mining activities were limited in depth by groundwater. It is thus reasonable to expect that some old mines and lead ranges may contain ore below the old workings. Nor is it likely that all ore above groundwater level in and adjacent to the old mines was found and extracted. Some of the old lead ranges can undoubtedly be extended, as has been done recently on the Dooling range, two miles north of Galena. Undiscovered parallel crevices also may exist in some mined areas. This is especially true below the previous limit of mining, because a crevice that is unproductive at one level may become ore-bearing at a deeper level. Finally, it is possible that in some instances the rib of rock left between closely spaced parallel workings or between openings at different levels on one crevice may carry enough galena to be minable.

Another potential source of galena associated with areas of old crevice mines is the surficial material above the bedrock. In 1947-49 the U. S. Bureau of Mines investigated the feasibility of stripping and beneficiating such material (Grosh, 1951). The terrain treated had been extensively prospected and mined by shallow pits and was therefore pitted and hummocky. The

material excavated was waste from old operations and previously untouched weathering residuum. Both were found to contain galena. The investigation indicated that a potentially minable grade of lead-zinc-bearing earth material occurred in sufficient quantity to support a stripping operation, but that upgrading of this material presents difficult problems.

Undiscovered New Deposits

It is significant that the majority of the areas of old lead diggings lie along stream valleys, as can be seen by comparing plate 1 with a topographic map. Such a situation is to be expected, both because stream valleys cut into the earth and provide natural "exploration trenches" and because areas of bedrock outcrops are limited virtually to stream beds and valley walls. Probably the most favorable places to look for new deposits, therefore, is under the uplands in the same direction of strike as that of known productive ranges. The extensions of the trends, however, may not provide what early miners called "openings" where mining was relatively easy in the soft, disintegrated rock with its loose chunks of galena. Instead, the deposits may occur in harder rock because they are farther below the surface where oxidation and weathering processes have not reached them. There is no geological reason, however, why there should be less galena along the unweathered crevices than along those in soft rock.

Under uplands there may be unknown areas of crevice deposits whose outcrops have not been found in valleys. This category would include the areas covered by Maquoketa Shale. A glance at the geologic map (*in* Trowbridge et al., 1916) shows that the Maquoketa and Maquoketa-Silurian uplands which border the drainage basins of the Galena River and its tributary East Fork also limit the main lead-producing area. It will be noted, also, that the outlying lead-producing areas, such as those at Elizabeth and Apple River, are along valleys where streams have removed the Maquoketa Shale and cut down into Galena Dolomite. Although it is true that the

valleys in Galena Dolomite east of the main producing region contain only a few areas of lead mining, it is nevertheless apparent that the high ridges between them and the main producing area may overlies other deposits. The main deterrent to prospecting the Maquoketa-covered areas, however, is the lack of an economically feasible method of locating the crevices in the underlying Galena Dolomite.

PROSPECTING METHODS

Prospecting methods are here classified as underground and surface methods, the reference being to the location of the person using the method. Drilling from the surface of the ground is generally classed as a subsurface method but is here treated as a surface method in order to distinguish it from drilling initiated from an underground excavation, such as a shaft or drift.

Underground Methods

Underground methods of prospecting consist of drilling and excavating. These methods are limited to areas with existing workings, although underground prospecting may be started in a new area once the presence of mineralization has been established. In an area of old workings, excavating may consist of extending the old drift along the crevice, cross-cutting at right angles to the crevice in search of neighboring parallel crevices, or sinking to explore for deeper bodies of ore.

Underground drilling for crevice deposits has limitations, chiefly that of space and the difficulty of recovering drilling samples. The common types of drilling machines that may be operated in the limited space are diamond drills and air-powered percussion drills. With both types it is difficult to recover samples from the soft or cavernous ground of the crevice orebodies. Exploration drilling underground, however, can be useful in finding neighboring parallel crevices, as the rate of drill penetration changes when the bit passes from hard dolomite into soft or open-crevice ground. Information on the presence or absence of mineralization in the neighboring crevice discovered in this

way must be gained by cross-cutting to it, but the preliminary drilling will save needless excavating in the event that no open crevices exist nearby.

A promising recent development in prospecting techniques is the practice of freezing unconsolidated materials so that a core can be obtained. The freezing method is presently in use in the Colorado Plateau uranium province, and it is expected that the costs of this technique will be brought down to that of ordinary diamond drilling.

A more remote possibility is the use of the auger-type rock drill. At present it is used successfully in the softer rocks, such as shales, and it seems probable that an auger could recover samples in soft crevice ground. Therefore, development of an auger bit capable of satisfactory progress in dolomite would offer another promising exploration tool.

Surface Methods

Surface prospecting methods include observation of surface phenomena, shallow excavations, drilling, and geophysical and geochemical methods.

Observation of Surface Phenomena.—Signs of mineral-bearing crevices, ranging from outcropping veins of galena to mere suggestions of crevices, such as lines of heavier vegetation, are sought in surface prospecting.

Outcrops of veins or other types of ore occurrence are rare. The more usual surface expression of a mineralized crevice is a vertical fracture filled with a reddish brown or orange dolomite sand-clay mixture that the miners call ocher. Where no bluff-type outcrops are available, rocky hill slopes with only a thin veneer of soil may show telltale ocher.

Most of the surface of the lead-producing area, however, is covered by a few to 10 or more feet of a wind-blown silt of glacial origin called loess that hides most of the bedrock and its mineralized crevices. In such areas sink holes, although not common in terrain underlain by the Galena Dolomite, may be related to the presence

of crevices. Owen (1840) mentions that "a small longitudinal depression or miniature ravine, on a hillside may be a symptom" of a crevice. More significant perhaps is a sharp jog or bend in a hillside gully such as would be likely to occur if a gully that started on a loess-covered surface encountered, on cutting down to bedrock, a pre-existing crevice-directed gully of different orientation. In general, little significance can be attached to the sharp, straight gullies on steep hillsides, whether there is a heavy loess cover or not, because this is the normal pattern of drainage on steep slopes.

Botanical evidence, such as the "lead weed" that was supposed to grow only where there was a source of lead in the soil, has been largely discounted. More generally, however, a narrow belt of abundant vegetation may reflect the existence of an underlying crevice.

The observational method is more likely to be useful in outlying areas where the terrain probably has not been searched as thoroughly as in the main producing area. It is worth noting, however, that geologic features that were hidden from view many years ago may have become visible today through erosion, and that for this reason localities within the main producing area that were passed by in former times might now exhibit more encouraging signs.

Surface Excavations. — Excavations to bedrock, such as trenches and test-pits, are useful in both known-productive and untested areas. In areas of former operations, surface excavations may locate extensions of old crevices and ranges. In untested areas, surface excavations may substantiate the presence of crevices indicated by less direct means. Residual ore at the surface of the bedrock, indicating the possibility of a "patch" deposit, also will be detected by removal of overburden. The chief disadvantage of surface excavations is that ore-bearing crevices may go unnoticed if the surface of the ground does not intersect a mineralized portion of the crevice. As mentioned, the iron sulfide in the deposits furnishes sulfuric acid on weather-

ing and thus greatly facilitates the breakdown of the dolomite wallrock, leading to the soft, iron-stained zones so characteristic of the crevice deposits. An unmineralized portion of the crevice, however, may remain tight, as seen in mine roofs, and be indistinguishable from any other joint in the rock.

Drilling. — As considered in this report, drilling pertains both to sampling of the overburden by means of an auger and to sampling of the bedrock and its contained ore deposits with rock drills of various types.

The soil auger generally serves the same purposes as surface excavations. Open crevices can be detected by abnormally deep penetrations of the drill, and any residual galena will be brought up in the auger samples. The advantages of the auger over actual excavations are speed and economy. The disadvantage is, of course, that the prospector cannot directly observe the bedrock surface but can only draw indirect conclusions from the drilling evidence. On the point of prospecting by auger for surface residual deposits, however, the U. S. Bureau of Mines surface lead study (Grosh, 1951) was encouraging. It was found, by comparing analyses of auger samples with analyses of the subsequently excavated earth material, that the auger samples gave a good indication of the amount of residual galena at the top of the bedrock.

Sampling the bedrock at depth by means of rock drills affords the only positive evidence of ore below the bedrock surface, aside from the much more expensive process of underground excavations. Any of the types of rock drills commonly used for prospecting are capable of penetrating and sampling the Galena Dolomite, but the difficulty of obtaining samples from the soft, often cavernous, weathered ore zones has favored the use of the churn drill in the Upper Mississippi Valley district. The manner of sampling with the churn drill, essentially a bailing-out of the hole, generally allows the recovery of most of the sample or at least enough of it so

that the prospector can tell whether or not there is mineralization.

The diamond drill has been tried by private companies and by the Bureau of Mines (Holt, 1948) but was not entirely satisfactory because it was difficult to recover core in the soft ore-bearing ground. Holt achieved partial sample recovery by casing the hole in soft or porous ground and collecting the sludge carried in the returning drilling water.

If the freezing method of coring unconsolidated material can be made cheaper, an important prospecting tool will become available. The chief disadvantages of the churn drill—ability to drill only vertical holes, and recovery of samples that only approximately represent conditions below ground—will no longer plague crevice prospecting. Freezing will make inclined core drilling practical and make it much easier to prospect new areas, as considerable widths of ground can be sampled with one hole of only moderate length, whereas a churn drill can explore an area only the width of the hole.

Drilling from the surface is useful in both known and new areas. In areas where there has been previous mining, the drill may be used to test the extensions of crevices and ranges or to explore for suspected parallel crevices. It can also be used to test the crevices below old workings. In new areas drilling may be used to substantiate and explore the crevices indicated by surface evidence.

Geophysical Methods. — Geophysical methods of prospecting consist of electrical, magnetic, and gravimetric procedures. Of the three, electrical methods probably have the best chances for success with the crevice lead-zinc deposits. Magnetic methods are not applicable because of the absence of magnetic minerals in the ores, and gravimetric methods are of uncertain value because of the small size of most of the orebodies. Descriptions of these methods may be found in Heiland (1946), Jakosky (1940), or any other authoritative work on geophysical prospecting.

Only the electrical geophysical methods have been tried on the crevice deposits.

Some years ago the Illinois State Geological Survey investigated the measurement of earth potentials as a method of locating crevice orebodies (Dobrovolsky, 1949, 1950). Employing both the *self-potential* and *applied-potential* methods, Dobrovolsky found that the presence of ore was indicated but that in most instances the electrical anomalies were offset 25 to 50 feet from the line of drill holes that marked the orebody. As the two deposits investigated were for the most part below the effective depth (50 feet) of the methods used, the results were inconclusive. In view of the fact that anomalies were detected at these excessive depths, it may be that the methods could successfully locate deposits within 50 feet of the surface.

The 50-foot depth limitation makes the method unsatisfactory for use on the uplands where the bedrock is either the Maquoketa Shale or the topmost part of the Galena Dolomite. At such places, deposits in the Dubuque Member, the upper part of the Galena, might be close enough to the surface to be detected, but if the deposits are below the Dubuque, the potential method is not believed likely to give definite indications of their presence.

Private companies have tried electromagnetic methods on the deeper lying flat-and-pitch deposits but are not known to have tried them on the crevice deposits. The results of their investigations have not been made public.

Geochemical Methods. — Methods of searching for metalliferous deposits by the detection of trace amounts of the metals in soils and rocks overlying the orebodies have been termed *geochemical* prospecting.

The most popular variation of geochemical prospecting, and the most promising for the detection of the crevice deposits, is soil testing by use of a colorimetric indicator called dithizone (diphenylthiocarbazone). A solution of dithizone in carbon tetrachloride or some other suitable organic solvent is a deep green color. When a soil sample containing traces of the heavy metals (lead, zinc, and copper) is introduced into the solution, the color changes, ranging from green through blue

to red, and the degree of change indicates the amount of the metals in the sample.

A field procedure involving acid digestion of the sample and necessitating a field laboratory has been described by Huff (1951) and tried by Kennedy (1956) in Wisconsin with promising results. A simpler and more rapid variation, which may be just as effective for the crevice deposits, has been developed by Bloom (1955). His method involves only shaking the soil sample for 5 seconds in an ammonium citrate solution, to which has been added a solution of dithizone in xylene that floats on top of the mixture and separates the colorimetric indicator from the sediment in the bottom of the test tube. A field trial of Bloom's method in northwestern Illinois over the deeper zinc orebodies proved that the sensitivity of the method is adequate, but no attempt was made at that time to investigate the crevice deposits.

Biogeochemical Methods.—A variation of the geochemical method, wherein the vegetation is analyzed for its metal content, is called *biogeochemical* prospecting (Warren and Howatson, 1947). Prospecting by a biogeochemical method was tried by the Illinois State Geological Survey some years ago in the vicinity of a small lead mine on the Hutchings property in the E $\frac{1}{2}$ sec. 19, T. 28 N., R. 2 E. The leaves of the hazel bush, *corylus*, which was liberally distributed over the area, were tested by shaking them in purified water with a dithizone-CCl₄ solution. By plotting on a map the observed color reactions, a pattern of broad bands was obtained that could be interpreted as showing an alignment of stronger reactions roughly parallel to one of the crevice directions observed in the mine. An area of stronger reactions was indicated over the mine itself.

To evaluate the possibility of using more than one kind of leaf in an area where no one type of plant had a favorable distribution, other trees and bushes over the Hutchings area were tested. It was found, as expected, that the degree of color-change

in the dithizone was affected as much by the kind of plant as by the plant's location. Therefore, in order to make the method effective, the area to be tested must be fairly well covered by a single species. It was felt that, in general, the method showed some promise, but that its use in northwestern Illinois is limited because of the relative scarcity of heavily wooded or brush-covered areas.

APPLICATION OF PROSPECTING METHODS

The discovery of additional crevice deposits in northwestern Illinois depends on the selection of the best prospecting method or methods for the area to be examined. An area of former lead production where the presence of mineralization has already been established affords the best possibilities for additional deposits, either on extensions of the known crevices or below the old workings. If the former workings are reasonably well located by lines of pits and shafts on the surface, the location of the crevices becomes a simple matter, and churn drills can be used to explore the extensions. It may also be worthwhile to clean out one or more old shafts to determine the extent of the old workings and to afford stations from which further underground exploration may be initiated. If the area has been completely dug over and presents a hummocky surface with no distinct alignments of the pits, the location of the main crevices is more of a problem. Trenching would probably be the most practical method, but soil augering could also be used. On the periphery of such an area, where the spacing of the pits is less dense, alignments may become evident so that drilling can be used to advantage.

In areas without old workings less direct methods of prospecting must be used. Observations of natural phenomena may be of use where there is little loess cover, but geophysical and geochemical methods generally are of more use.

Little is known of the applicability of geophysical methods to prospecting for

crevice deposits, but it appears that the self-potential and applied-potential methods may be useful as reconnaissance methods in establishing the presence of mineralized crevices in an area. Because of their 50-foot depth limitation, the potential methods would not be entirely satisfactory for use on the uplands.

Geochemical methods have the advantage over electrical methods in that only the presence of lead and zinc ions is needed, and the orebody need not have electrical continuity or possess a potential gradient. For these reasons, it is possible for soil-testing procedures to detect thoroughly oxidized orebodies.

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CREVICE MINES AND PROSPECTS NOT DESCRIBED IN TEXT

Name (Reference) ^a	Sec.—T-R	Mine or prospect	Strike of crevice	Stratigraphic position of base of ore	Type of ore ^b	Depth of shaft (ft.)	Remarks
Fox River Valley (Bain, 1905, 1906; Willman et al., 1946)	NW NE 25-29N-1W	M	E-W	Probably upper (non-cherty) Prosser	Pb-Zn	95 65	Importance of production unknown.
Red Bird (Files) ^a	S1½ NE 36-29N-1W	M	N80W	Near base of Stewartville (?)	Pb	28	<i>Receptaculites</i> common 10' above floor.
Vinegar Hill (Bain, 1906)	SE NE 36-29N-1W	M	E-W	62' below base of Maquoketa or 20' above base of Stewartville	Pb (Zn)	29	On same range as old Madison Syndicate. Breccia ore. This is not the better-known Vinegar Hill zinc mine.
Furlong (Files)	N1½ Frac. 20-29N-1E	P	E-W	At or above TC ^c	Pb	70 55 55+	Small production reported late 1800's.
Paragon (Cox, 1914; Willman et al., 1946)	SW NW 23-29N-1E	M	E-W	Deepest level 25-50' above "oil rock"	Pb (Zn)	130 110 110	On Capt. Gear range. Mine very little developed.
Schaber (Files)	NW SE SE 33-29N-1E	P	N80-85W	About 70' below TC	Pb-Zn	90±	Recent reopening of old workings.
Spensley (Files)	N1½ NE NW 33-29N-1E	M	E-W	Probably between TC and base of Dubuque	?	100± 60	Reported former lead production. Open cut 300-400 feet long. Unknown production.
Veta Grande or Vista Grande (Bain, 1906)	E½ Near N. line, frac. 15-29N-2E	M	?	155' below base of Maquoketa, 30' below TC	Pb	115	Bain (1906) shows it in Ill., but Alexander (1916) maps it in Wis. Small production.
Glanville (Bain, 1906)	NE NW 24-29N-2E	P	None	Maquoketa Shale	Zn	Adit	Sphalerite and barite as vug fillings in dolomite layers.
Steigner (Files)	NE SW 33-29N-4E	P	E-W	Probably near base of Dubuque	Pb	26	Small production.
Big Indian (Willman et al., 1946)	S1½ NE 1-28N-1W	M	N75W av.	2 horizons, one about 20' above TC, other at TC	Pb-Zn	30- 90	Four shafts. Proportions of Pb and Zn varied locally. Sometimes called Dooling range; location of present Dooling mine.
Comstock (Files)	NE SW 1-28N-1W	M	?	Not reported	Pb (Zn)	?	200 yds. south of Oldenburg. Said to be important Pb producer prior to 1900.
Dooling range (Files)	S1½ NE 1-28N-1W	M	N85W av.	About 20' above TC	Pb	Shallow	Three shafts. 400' south of present Dooling Pb mine.
Oldenburg (Bain, 1906; Willman et al., 1946)	NE SW 1-28N-1W	M	E-W	Just below TC	Zn	100 140	Honeycomb ore.

^a "Files" refers to field notes in Survey files. This information may be based on direct observation, on interviews with property owners, with mine operators, or miners associated with the mine or prospect.
^b Relative amounts of lead and zinc minerals detected or reported in the ore: Pb—exclusively lead minerals; Pb(Zn)—predominantly lead minerals; Pb-Zn—lead and zinc minerals roughly equal in amount; Zn(Pb)—zinc minerals predominant; Zn—exclusively zinc minerals.
^c TC = top of cherty portion of the Prosser.

APPENDIX—Continued

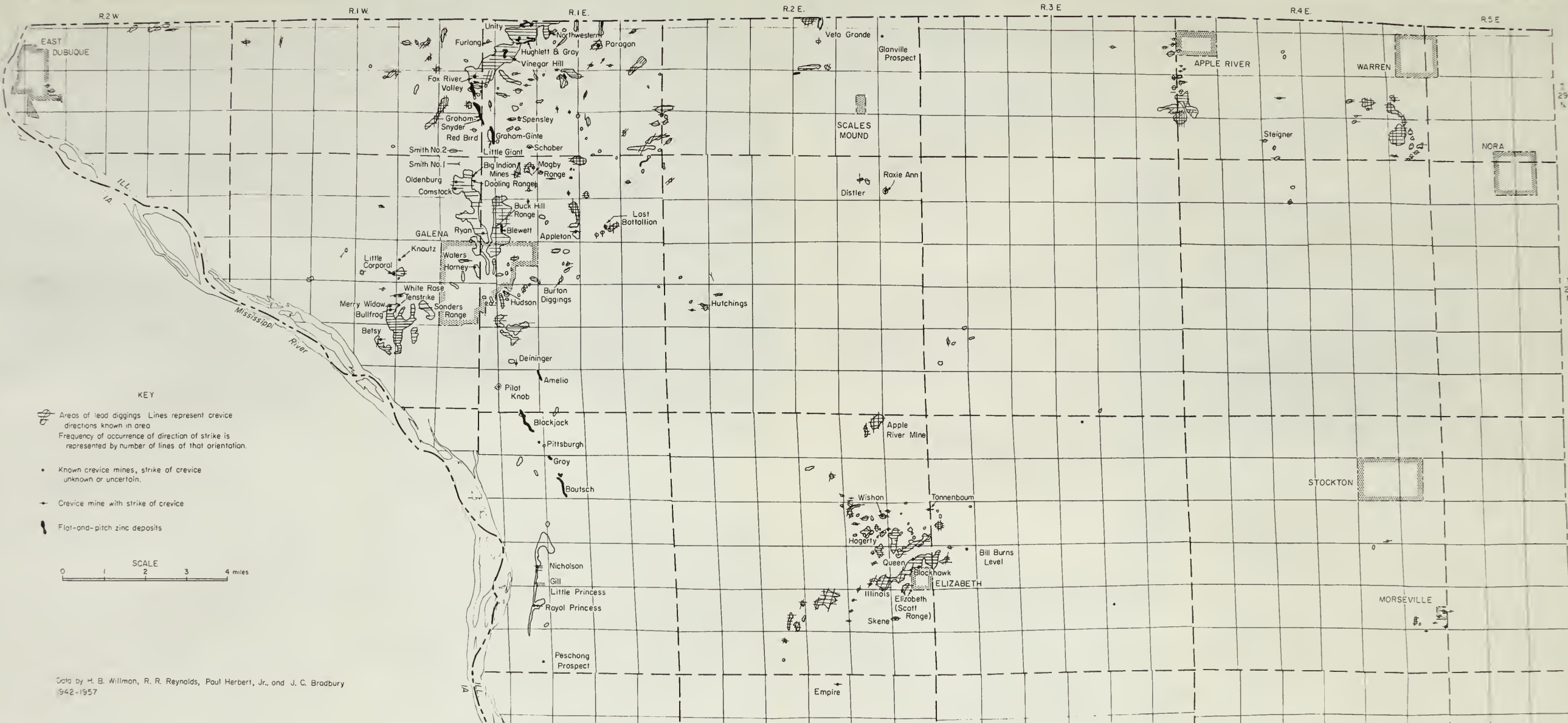
Name (Reference) ^a	Sec.—T-R	Mine or prospect	Strike of crevice	Stratigraphic position of base of ore	Type of ore ^b	Depth of shaft (ft.)	Remarks
Waters (Bain, 1906; Willman et al., 1946)	Near cen. 13-28N-1W	M	E-W	Slightly above TC	Pb-Zn	100	Early Pb production. Later produced Zn as carbonate.
Knautz (Files)	NW NW SW 14-28N-1W	M	?	Not reported	Pb	25	Small production. Just north of Little Corporal.
Little Corporal (Bain, 1906; Willman et al., 1946)	NE SE SE 15-28N-1W	M	N80W	About 20' above TC	Zn	110	Workings 400' long.
Bull Frog (Willman et al., 1946)	NE SE 22-28N-1W	M	N85E	Workings above TC	Zn	37	Breccia ore. Small production. Mining was at depth of 22'.
Merry Widow (Cox, 1914; Willman et al., 1946)	NE SE 22-28N-1W	M	N75E	Principally in upper 25' of cherty Prosser	Pb (Zn)	70	Major producer. 200' north of Bull Frog mine.
White Rose (Willman et al., 1946; Files)	SE NE 22-28N-1W SW NW	M	N85E	Upper part of cherty Prosser	Pb (Zn)	Variable	About ¼ mile north of Merry Widow. Deepest shaft 70'.
Tenstrike or Webber and Cring (Bain, 1906; Willman et al., 1946)	23-28N-1W NW SW 23-28N-1W	M	N75E	Same as Merry Widow	Pb (Zn)	65	Same crevice as Merry Widow.
Sanders (Files)	NE NW SE 23-28N-1W SW NE	M	E-W?	Not reported	Pb	?	On Sanders range. Much Zn reported from other diggings on property.
Betsy or Weinschenk (Willman et al., 1946)	27-28N-1W SE NE	M	E-W	About 25' above "oil rock"	Zn	72 102	Zn carbonate ore.
Magby range (Files)	4-28N-1E N½ S½ 8-28N-1E	M	N50W	Probably upper Prosser	Pb	Variable	8-10 shafts, deepest 40', and one open cut. Worked over 100 years ago.
Buck Hill range (Files)	NW NE 9-28N-1E NE NE	M	N80W	Upper Prosser	Pb	Variable	Includes open cuts. Other ranges in Buck Hill area shown on Pl. 1.
Drill hole (Cox, 1914; Willman et al., 1946)	10-28N-1E SE NE SE	M	N-S	20' above "oil rock"	Pb (Zn)	237	Ore mostly galena in crevice and flat openings along bedding planes.
Sheboygan (Cox, 1914; Files)	11-28N-1E NW NW	P	?	At TC	Pb	140	No measurable production.
Lost Battalion (Files)	21-28N-1E NE SE SW	M	E-W N-S	About 50' below TC	?	50	Pb and Zn both occur, but no report of relative amounts.
Hudson quarry (Files)	28-28N-1E NW SW NW	P	Near E-W	Few feet below TC	Zn (Pb)	None	Smithsonite and galena in shear zone.
Deiningner (Files)	NE SE SW 28-28N-1E	M	N-S	Probably upper Prosser	Pb	90±	One of 5 or 6 old diggings. 200' drift.
Pilot Knob or Glen Ridge (Willman et al., 1946)	NW SW NW 33-28N-1E	M	Near E-W	30' above "oil rock"	Zn	112 96	Elliptically shaped body of breccia ore.

Name (Reference) ^a	Sec.—T-R	Mine or prospect	Strike of crevice	Stratigraphic position of base of ore	Type of ore ^b	Depth of shaft (ft.)	Remarks
Roxie Ann (Files)	SW NW SW 1-28N-2E	M	E-W?	About 10' below TC	Pb	80	Reportedly encountered Zn at 150' at later date, but not mined because of strong water flow.
Distler (Files)	Center 2-28N-2E	M	E-W	About 40' above TC or 5' below Stewartville	Pb	50	A few other pits and an open cut along same crevice.
Gill (Files)	S½ SE 21-27N-1E	M	N85W	Not reported	Pb	Adit	100-200' north of Little Princess.
Royal Princess (Bain, 1906; Cox, 1914; Willman et al., 1946)	Cen. E½ 28-27N-1E	M	E-W	Upper Prosser, top of ore 60' above TC	Pb-Zn	?	Produced the only zinc reported from California Diggings area.
Peschang (Files)	SW NE SE 33-27N-1E	P	?	In Dubuque	Pb	155 265 None	Cubes of galena in "ocher."
Tannenbaum (Files)	SE NE NE 13-27N-2E	P	E-W	Ca. 65' below TC	Pb	60	Old workings encountered 20' west of shaft.
Hagerty (Cox, 1914)	SE 14-27N-2E	M	E-W?	Not reported	Pb?	47	On Log Chain range. Old Hagerty ¼ mile east and said to be important producer.
Wishon (Bain, 1906; Cox, 1914)	SE NE 14-27N-2E	M	E-W	Just below TC	Pb	150	Pitches dip both north and south from main crevice.
Illinois (Cox, 1914)	SE SE 23-27N-2E	M	E-W	Not reported	Pb	110 130	On Richards range. Produced much Pb at 90' depth.
Blackhawk (Files)	SE 24-27N-2E	M	?	Not reported	Pb	127	In city limits at north edge.
Elizabeth (Cox, 1914)	SE SE SW 24-27N-2E	M	?	Not reported	Pb	150	On Scott range.
Kansas (Cox, 1914)	SW 24-27N-2E	M	?	Not reported	Pb?	127 200	On Van Meter range.
Riverside (Cox, 1914)	SW 24-27N-2E	M	E-W N-S	Not reported	Pb	135 160	On Pough range.
Queen (Bain, 1905)	SW NE 24-27N-2E	M	?	Not reported	Pb?	?	Location shown on Bain's Pl. III (1905).
Skene (Bain, 1906; Cox, 1914; Files)	NW SW 25-27N-2E	M	N83E	Lower workings reported in top of cherty Prosser	Pb	96	Crevice splits downward into 2 pitches, one dipping north, other dipping south.
Bill Burns Level (Cox, 1914)	NE NW NE 19-27N-3E	M	N-S	Near TC	Pb	25	Galena in small pockets, fractures, and bedding planes.
Empire (Cox, 1914)	Cen. NE 3-26N-2E	P	E-W	Not reported	Pb?	50 50	On Steel range.
Smith's Cave (Files)	S½ 2-24N-4E	M	?	Not known	Pb	Adit	Amount of production unknown. One mile west of Mt. Carroll.
Fulrath's Mill diggings (Files)	N½ SW NE 3-24N-4E	M	N37E S35E	About 10' below TC	Pb	2 Adits	Galena chiefly as cubes scattered along fractures. Small production around 1935.

ILLINOIS STATE GEOLOGICAL SURVEY REPORT OF INVESTIGATIONS 210

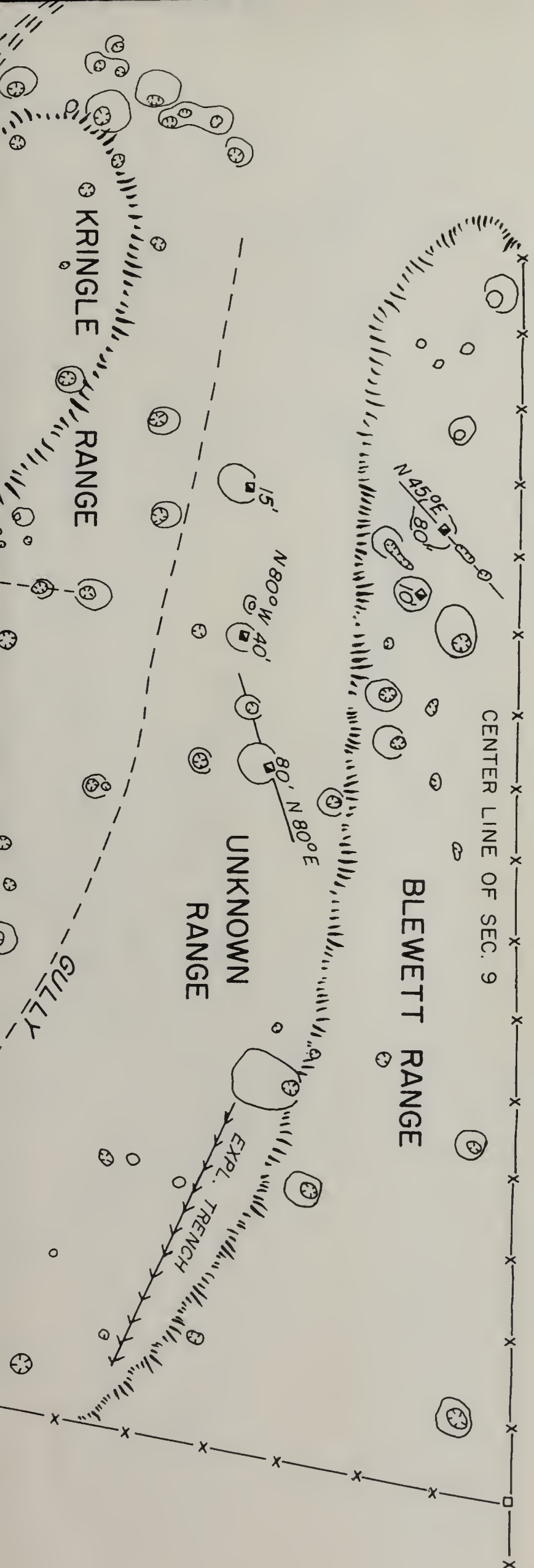
49 p., 6 pls., 11 figs., app., 1959





CREVICE LEAD-ZINC DEPOSITS OF JO DAVIESS COUNTY, ILLINOIS

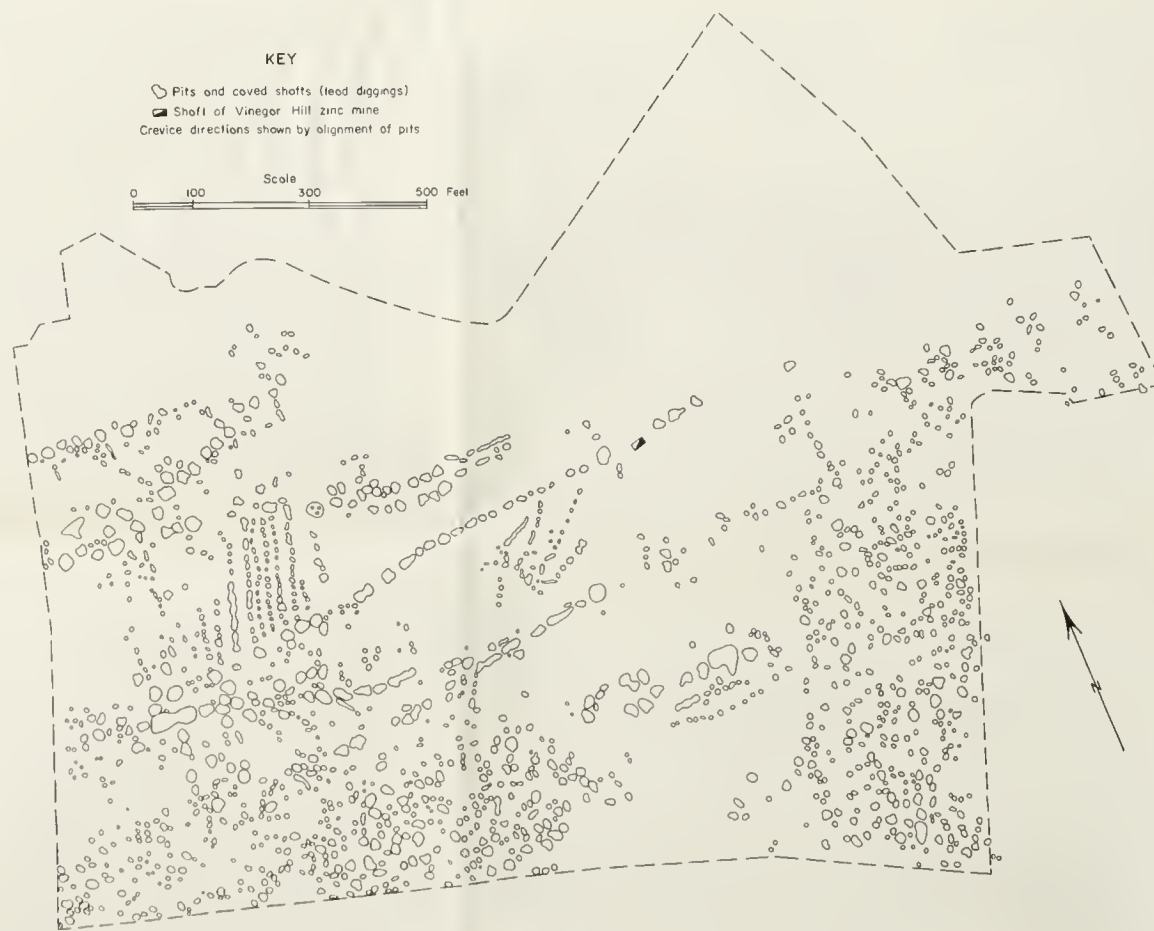
Report of Investigations 210, Plate 2





BUCK HILL (BLEWETT) MINE AND VICINITY

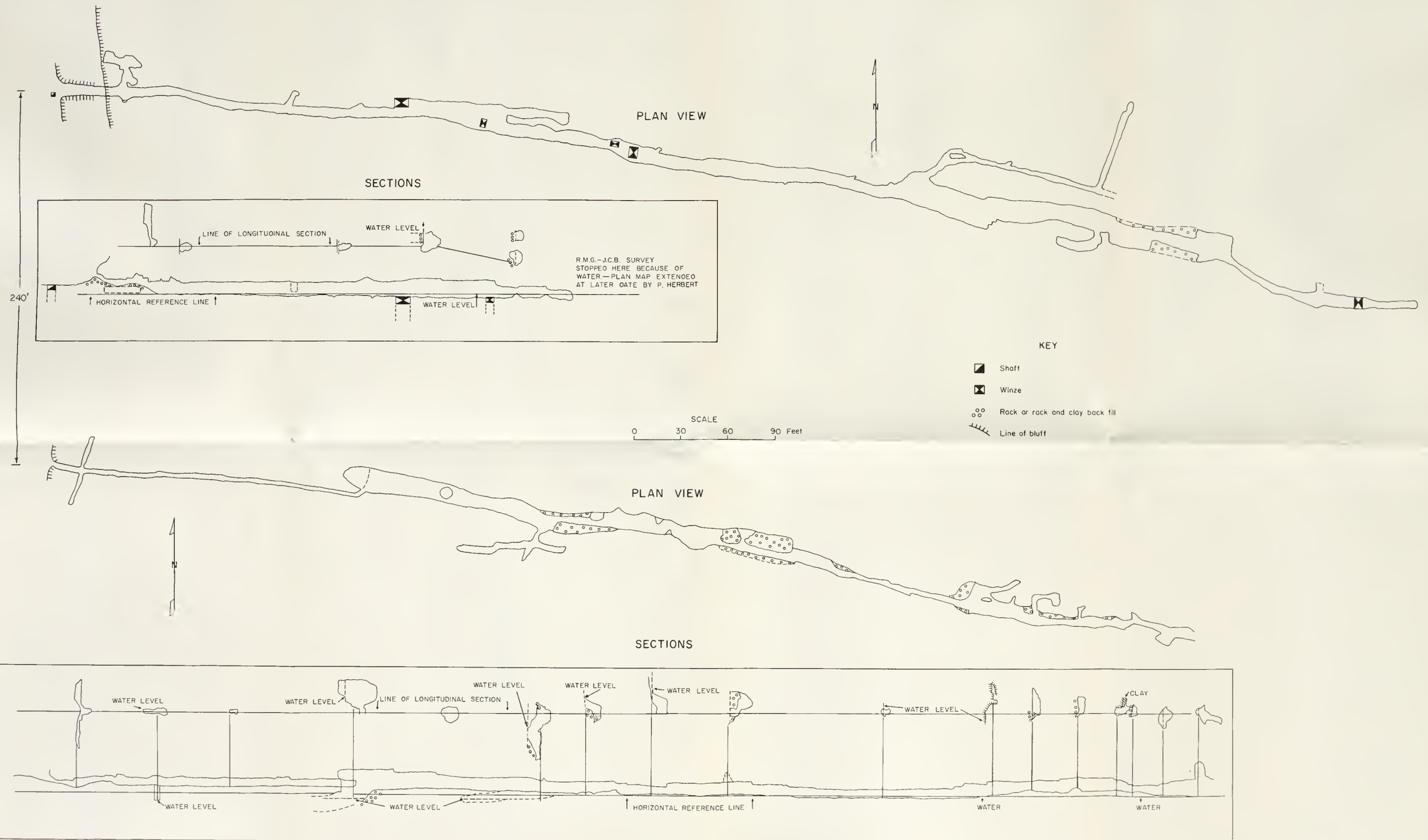
Locations of Lead Diggings
Parts of secs 8 and 9, T. 28 N., R. 1 E.



OLD LEAD DIGGINGS, VINEGAR HILL AREA

Report of Investigations 210, Plate 3





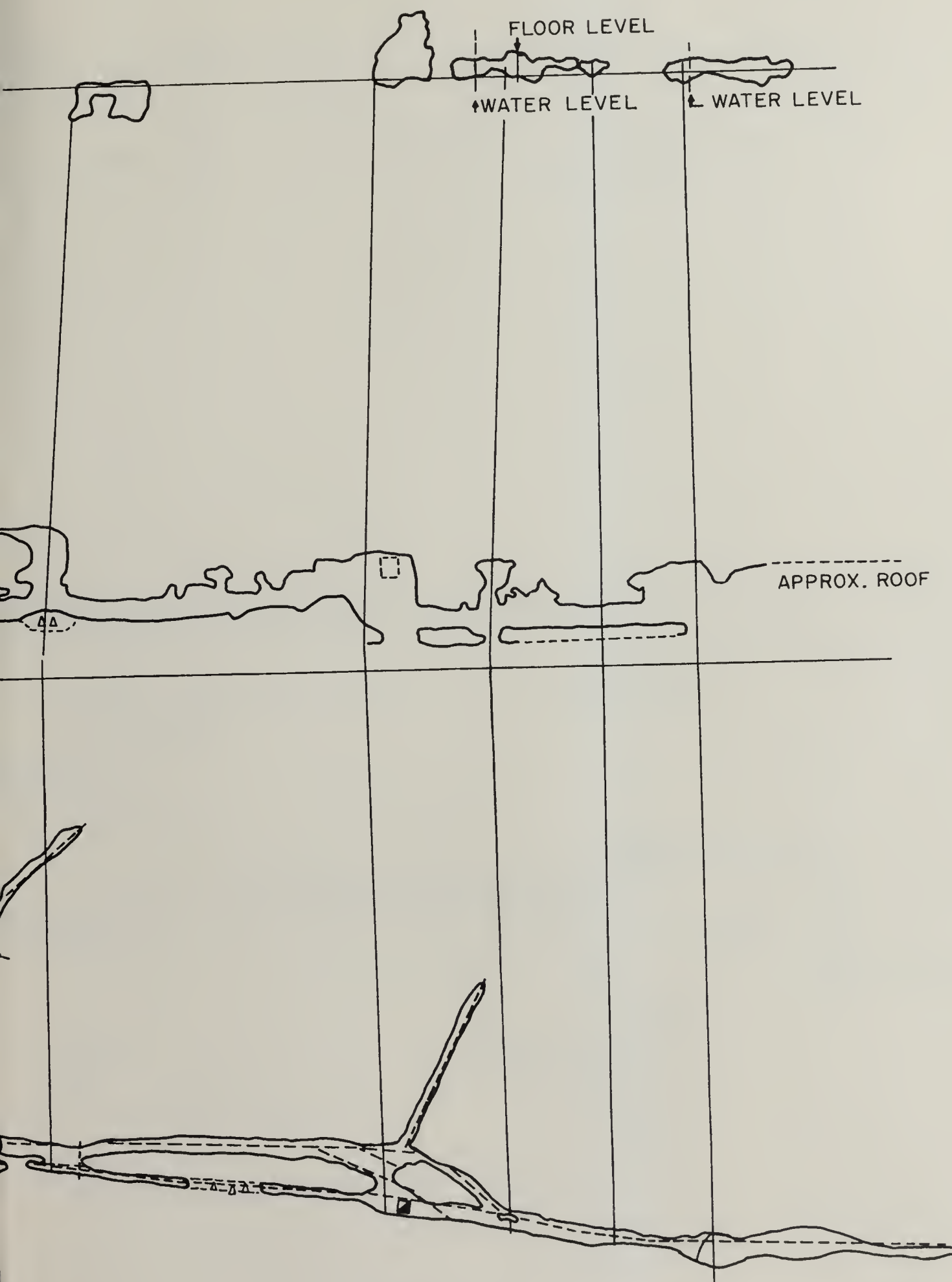
By R. M. Gagan and J. C. Bradbury, 1947

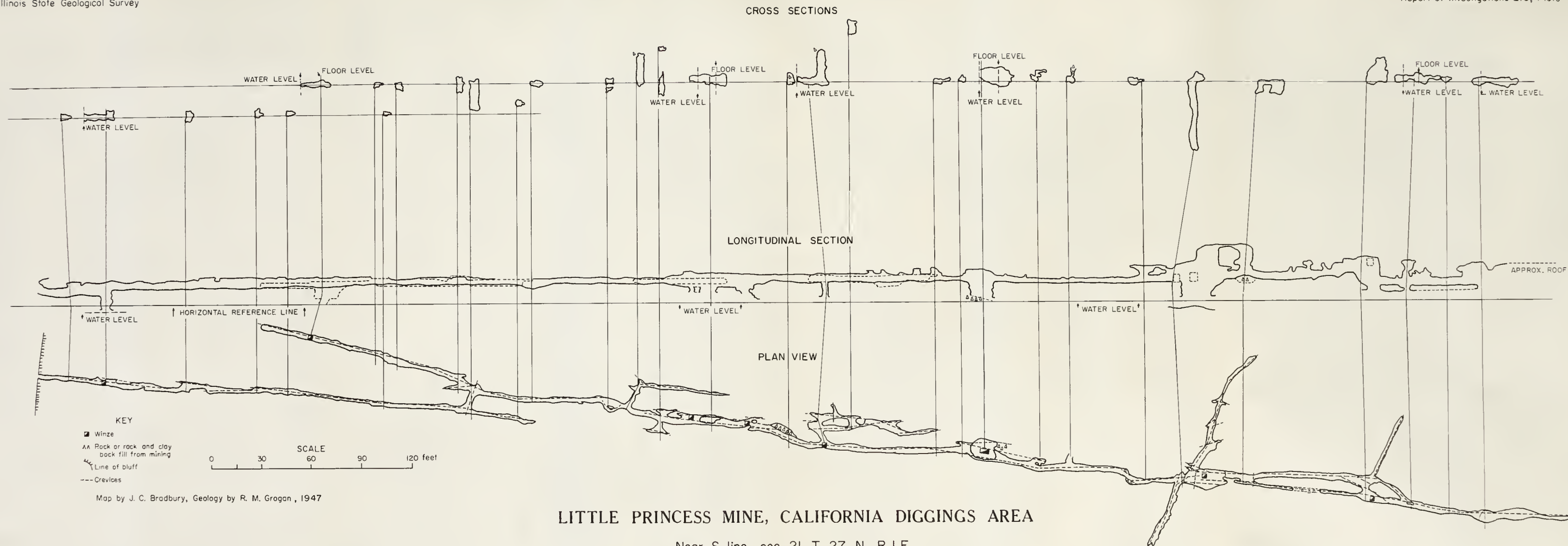
NICHOLSON MINES, CALIFORNIA DIGGINGS AREA

Plan and sections near center of E $\frac{1}{2}$ sec. 21, T. 27 N., R. 1 E.

Ja Daviess County, Illinois

Report of Investigations 210, Plate 4



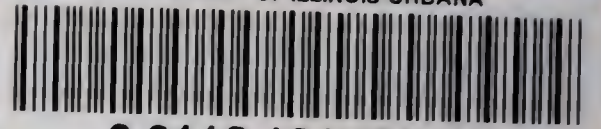


LITTLE PRINCESS MINE, CALIFORNIA DIGGINGS AREA

Near S line, sec. 21, T. 27 N., R. 1 E.

Jo Daviess County, Illinois

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